Underwater Noise

15. UNDERWATER NOISE

15.1. Introduction

This Chapter contains an assessment of the noise and vibration impact on several marine species, including mammals and fish, which inhabit the marine environment around the proposed jetty construction west of Point Lowly, Port Bonython and the wider Upper Spencer Gulf. Impacts on human divers who may utilise the underwater environment are also considered.

Construction noise, especially from impact piling activities and operational ship noise have been assessed as the most likely noise sources to cause an adverse impact to marine species and environment.

15.2. Legislation

There is no South Australian legislation specifically imposing restrictions on underwater noise levels; however there are items of legislation that indirectly place restrictions on underwater noise levels under certain circumstances. Commonwealth Legislation (the EPCB Act) and the SA National Parks and Wildlife Act 1972 provide protection to listed species (the listed species under the National Parks and Wildlife Act are the same as those listed under the EPCB Act), and hence cover the instance of environmental harm to listed species due to underwater noise. Some SA legislation (the Marine Parks Act 2007, Fisheries Management Act 2007) imposes restrictions on activities that will result in environmental harm to species within specific protected areas (i.e. marine parks and fisheries).

The SA Department of Planning, Transport and Infrastructure has prepared an Underwater Piling Noise Guidelines document that apply to any proposed piling operation within SA waters, which provide a current accepted best-practice approach to assessing and managing underwater noise, and clarifies the status of underwater noise emission with respect to the requirements of applicable Commonwealth and State legislation.

15.3. Methodology

15.3.1. Marine Species

The unusual combination of relatively warm water, high salinity and sheltered conditions in the northern reaches of Upper Spencer Gulf has led to the presence of ecological communities with tropical and subtropical affinities. The Gulf supports a productive marine ecosystem and a diversity and abundance of marine organisms, including listed threatened and migratory species, species of particular local conservation interest (such as the Giant Australian Cuttlefish (*Sepia apama*)), and species of commercial or recreational importance.

The Giant Australian Cuttlefish, although not a listed species, is of particular local importance as large numbers are attracted to the shallow rocky reef in the vicinity of Black Point and Point Lowly to breed between May and October each year.

Significant marine species occurring or potentially occurring in the Upper Spencer Gulf include:

Cetaceans

» Southern Right Whale

» Humpback Whale.

» Indian Ocean Bottlenose Dolphins

Pinniped

» Australian Sea Lion

Cephalopods

» Giant Australian Cuttlefish.

Sharks

» Great White Shark.

Fish

» King George Whiting

» Yellowfin Whiting

» Yellow-tail Kingfish

» Snapper.

Crustacean

» Western King Prawn.

These are the main species considered in this assessment; for further information on these species, refer to **Chapter 14, Marine Ecology**.

15.3.2. Ambient Noise Measurements

In the absence of any underwater ambient noise measurements taken as part of this study, or within the Upper Spencer Gulf, Wenz curves are proposed to be used to describe underwater typical ambient noise levels in the vicinity of the Project.

The Wenz curves (Wenz, 1962) are a family of curves showing typical ambient noise levels in open ocean areas for different sea state conditions and for different water depths from both natural and man-made noise sources. Refer to **Figure 15.3a** for a summary of the Wenz curves and typical noise sources contributing to the underwater ambient noise in each frequency region.

Note that the assessment criteria for underwater noise impacts are absolute level criteria – i.e. they are independent of the background noise – and hence knowledge of the existing background noise only affects the range at which noise levels from the Project will be inaudible, but does not affect the ranges at which potential adverse impacts will occur.

The Port Bonython area is a shallow water and high-energy coastal environment. The shallow water depth means that noise from the ocean boundaries (wind and wave noise) will be higher than in deep water.

The presence of several ports and industrial facilities in the region of Port Bonython (i.e. Whyalla, Port Pirie and Port Augusta) combined with the narrow width of Spencer Gulf means that underwater ambient levels in the region are expected to be at the upper boundary of the Wenz curves at low frequencies (i.e. following the “heavy traffic noise” curve shown by the dotted red line in **Figure 15.3a**.

Noise levels above one kilohertz (kHz) will largely be variable depending on the sea state and weather conditions.

15.3.3. Underwater Noise Predictions

The RAMSGeo parabolic equation (PE) propagation model was adopted for this study and was implemented using the Acoustic Toolbox (AcTUP v2.2L (Curtin University, 2013)). Parabolic equation models are most appropriate for low-frequencies (below 1000 Hz), and can model range-dependent bathymetry (i.e. water depth varying with range; most other models are limited to constant depth or are only valid at high-frequencies).

15.3.4. Assessment Criteria

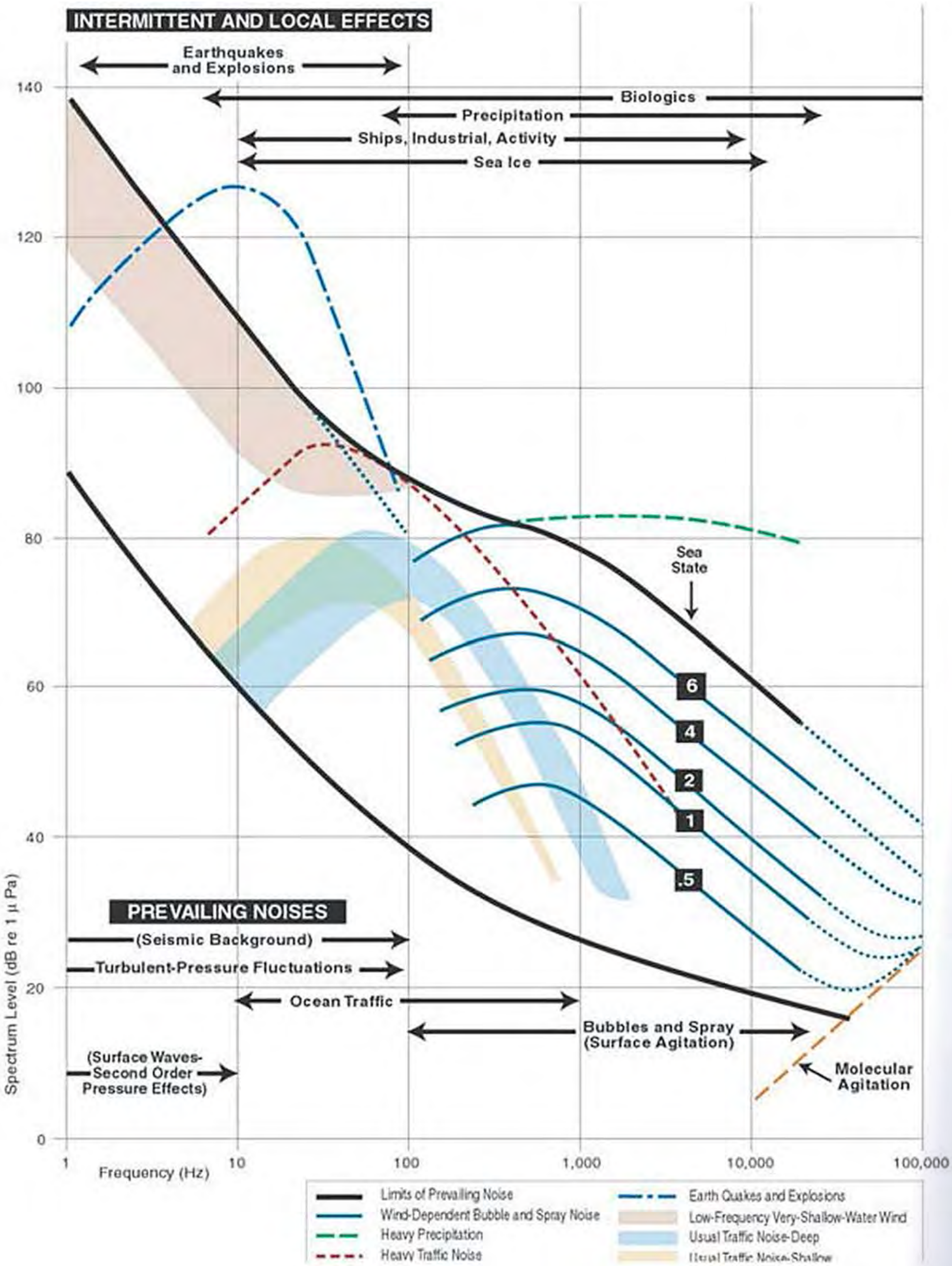
Noise exposure thresholds have been determined for each relevant species based on their sensitivity to underwater noise (Refer to **Section 15.4.3** for further information).

Based on these thresholds, Noise Assessment Criteria have been developed, as described in **Table 15.3a**.

Table 15.3a: Noise Assessment Criteria

Assessment Level	Criterion
Very High Adverse	Noise from construction or operational activities, in particular underwater piling that result in mortality or permanent threshold shift (hearing damage) which leads to mortality, permanent or long-term (greater than five years) disappearance of nationally and state significant species, including the Giant Australian Cuttlefish.
High Adverse	Noise from construction or operational activities, in particular underwater piling that result in mortality or permanent threshold shift (hearing damage) which leads to mortality or permanent disappearance of non-significant species or damage to human hearing.
	Noise from construction or operational activities, in particular underwater piling that result in temporary threshold shift or disruption to habitat, which leads to short term disappearance (less than five years) of nationally and state significant species.
	Noise from construction activities, in particular underwater piling that result in temporary threshold shift or disruption to habitat, which leads to long-term (greater than five years) disappearance of non-significant species.
Moderate Adverse	Noise from construction activities, in particular underwater piling that result in temporary threshold shift or disruption to habitat, which leads to short term (less than five years) disappearance of non-significant species.
Minor Adverse	Noise from construction or operational activities which leads to a temporary (less than one week) disturbance of significant or non-significant species.
Negligible	Noise from construction or operational activities does not have an impact on species or human divers.

Figure 15.3a: Wenz curves, adapted from Ocean Noise and Marine Mammals (National Research Council, 2003)



15.4. Background Information

15.4.1. Sensitivity of Marine Life to Noise

Various studies on marine animal behaviour, including reactions to noise, are available in the literature. Sound stimuli range from frequency-specific stimuli to explosions/seismic airguns. These studies have shown that underwater noise can have adverse behavioural or physiological effects on underwater life.

The adverse effects, in ascending level of impact (and in ascending order of noise exposure) are, broadly:

1) Auditory masking (the presence of noise causes important biological sounds to be obscured). This has generally short-term impacts, persisting only as long as the masking sound is on operation e.g.

- Missing out on feeding opportunities
- Impeded communication (social interaction, mating calls, etc.)
- Decreased ability to detect predators or danger.

2) Avoidance behaviour (animals becoming stressed and leaving the vicinity of the noise source).
This can have long-term adverse effects on a species, e.g.

- Disruption of migration, breeding or feeding patterns
- Separation of infant animals from adult animals (and consequent increased vulnerability to predators)
- In cases of chronic exposure, long-term physiological impacts due to prolonged increase in levels of stress hormones
- In extreme cases, physical injury or death if behavioural changes lead to vessel collisions or strandings.

3) Temporary hearing damage, due to fatigue/exhaustion of the auditory system. Hearing ability recovers over a timeframe of hours or days. This has short-term adverse impacts such as:

- Increased vulnerability to predators
- Disorientation (for species that rely wholly or partially on sound for navigation or hunting), reducing ability to feed and increasing the risk of stranding
- Reduced ability to communicate (disrupting group social behaviour, ability to hear mating calls.).

4) Permanent hearing damage, due to cell death of the auditory system (either physical damage to the hearing structures or nerve damage to the auditory nerve). This has similar impacts to temporary hearing damage, but the impacts are permanent rather than short term.

5) Physical trauma/injury (especially to gas-containing structures), which can lead to death.

6) Fatality.

15.4.2. Hearing Characteristics of Species

15.4.2.1. Marine Mammals

The hearing abilities of marine mammals are the best documented of all sea creatures. Behavioural audiograms (animal hearing capability measurements plotted against the frequency of sound, including hearing thresholds) have been taken for several species (Nedwell et. al, 2004). The effects of sound masking have been partially investigated, as has the ability of species to discriminate in terms of both frequency and direction of sound.

While the hearing abilities of most marine mammal species have been tested, only one or two individuals in each species have been studied, so variations in hearing ability among individuals is not known (Nedwell et. al, 2004).

However, available data shows reasonably consistent patters within the following groups:

- Mysticetes (Baleen Whales that have a filtering system) (“low-frequency cetaceans”) [e.g. Southern Right Whale and Humpback Whale]
- Small and medium-sized Odontocetes (toothed Whales and Dolphins) (“mid-frequency cetaceans”) [e.g. Bottlenose Dolphin]
- Pinnipeds, consisting of Phocinids (true Seals), and Otariids (Fur Seals and Sealions). [e.g. Australian Sealion].

15.4.2.2. Mysticetes

Mysticetes produce primarily low-frequency sound (below one kHz (Richardson, 1995)), although Humpback Whales and some other species produce sounds with frequencies above one kHz. Baleen whale vocalisations are a combination of low-frequency “moans”; noise-like impulsive “grunt” or “ratchet” calls, and complex “whale song” (National Research Council, 2003).

Very little data is available about the hearing capabilities of Mysticetes and no audiograms have been published in the available literature; however studies based on the physiology of Mysticete hearing mechanisms suggests that most Mysticetes can hear down to approximately 20 Hertz (Hz) (Ketten, 1997) with greatest hearing sensitivity lies in the range 1005000Hz (Ketten, 1997).

15.4.2.3. Odontocetes

Odontocetes (toothed whales) produce mainly high-frequency sound, a combination "clicks" used for echo-location and vocalisation "whistles" used for communication between individuals. Hearing ranges from existing Odontocete data have been shown to range up to approximately 110kHz, with greatest sensitivity in the range of 8–90kHz. Hearing is relatively insensitive below 1kHz, but is generally very accurate above this range – a Killer Whale tested by Hall and Johnson could detect a 15 kHz signal of approximately 30 dB re 1 µPa (Richardson et al, 1995). A graph of underwater audiograms of various Odontocetes is shown in **Figure 15.4a**.

Odontocetes appear to be largely insensitive to low-frequency sounds, with measured hearing thresholds generally greater than 100 decibels (dB) (relative to one micropascal (µPa) – i.e. dB re 1 µPa) at frequencies below 1kHz (Richardson et al, 1995)) but may be sensitive to some combination of low-frequency particle motion and pressure fluctuations when in the near-field of the acoustic source – in other words, they may 'feel' the sound through the movement of the water itself rather than 'hearing' it through their ears, but only when close to the source.

Unfortunately, studies are frequently inconclusive as to the precise level at which these impacts occur, and the level of sensitivity of different species to noise varies (Richardson et al, 1995).

Hence, it is often necessary to adopt a conservative approach to managing noise impacts (under the Precautionary Principle) since the actual safe level of noise exposure is not always known.

15.4.2.4. Pinnipeds

Pinnipeds produce underwater vocalisations sounding like "barks" or "clicks". The dominant frequency range is from 250Hz to 2 kHz (Richardson et al, 1995) while the frequency range of greatest sensitivity for Pinniped hearing is approximately one kHz–30kHz. Pinnipeds are more sensitive than Odontocetes to low-frequency sound below one kHz. Underwater audiograms of various Pinnipeds are shown in **Figure 15.4b**.

15.4.2.5. Human Divers

The human auditory system is significantly less-sensitive underwater than in air. The effectiveness of the auditory system is further degraded if diving equipment obstructs the ears or face (e.g. diving with a hood or full facemask). Underwater hearing thresholds of human divers are shown in **Figure 15.4c**.

Figure 15.4a: Underwater audiograms of various Odontocetes, adapted from Nedwell et al, 2004

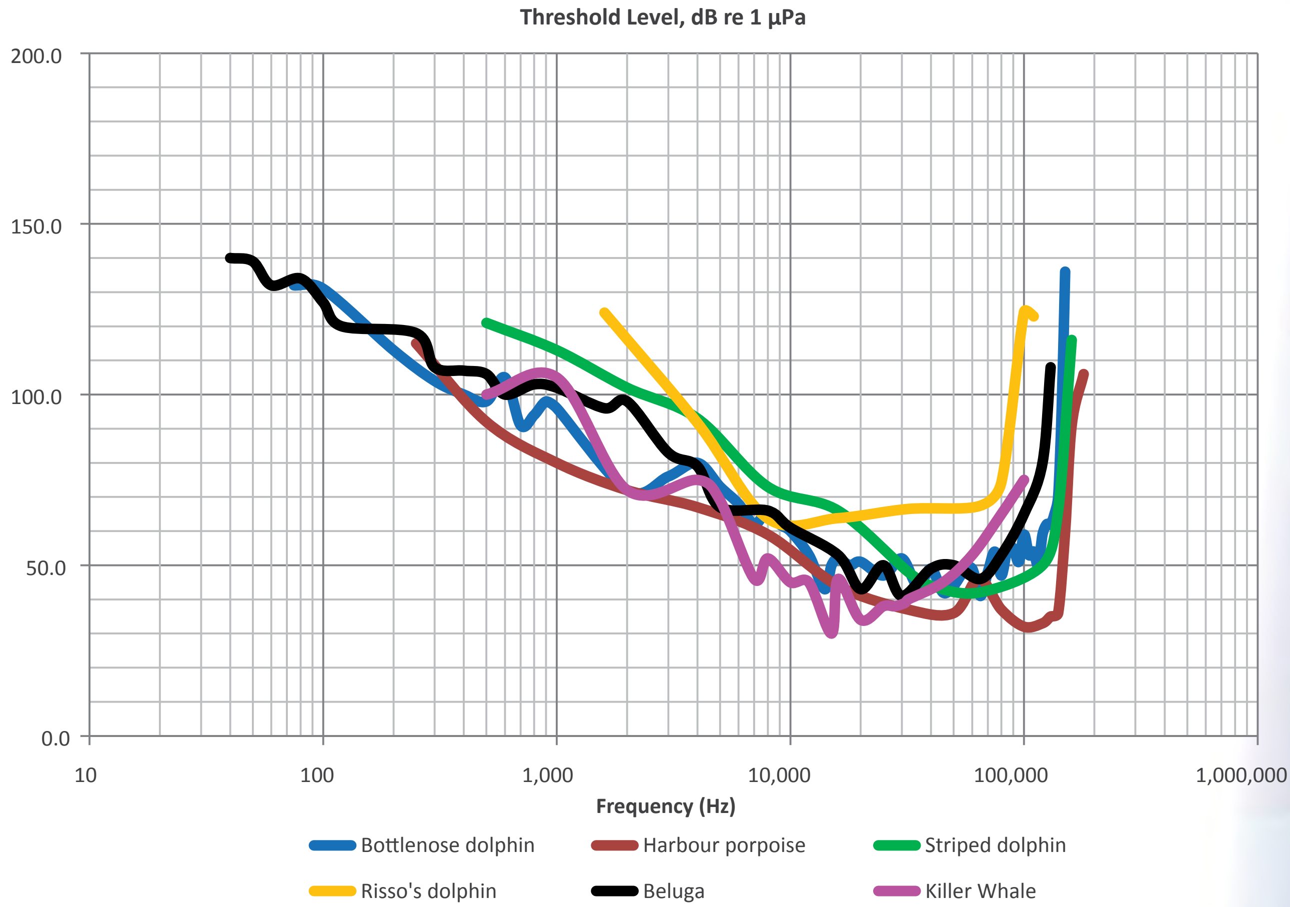


Figure 15.4b: Underwater audiograms of various Pinnipeds, adapted from Nedwell et al, 2004

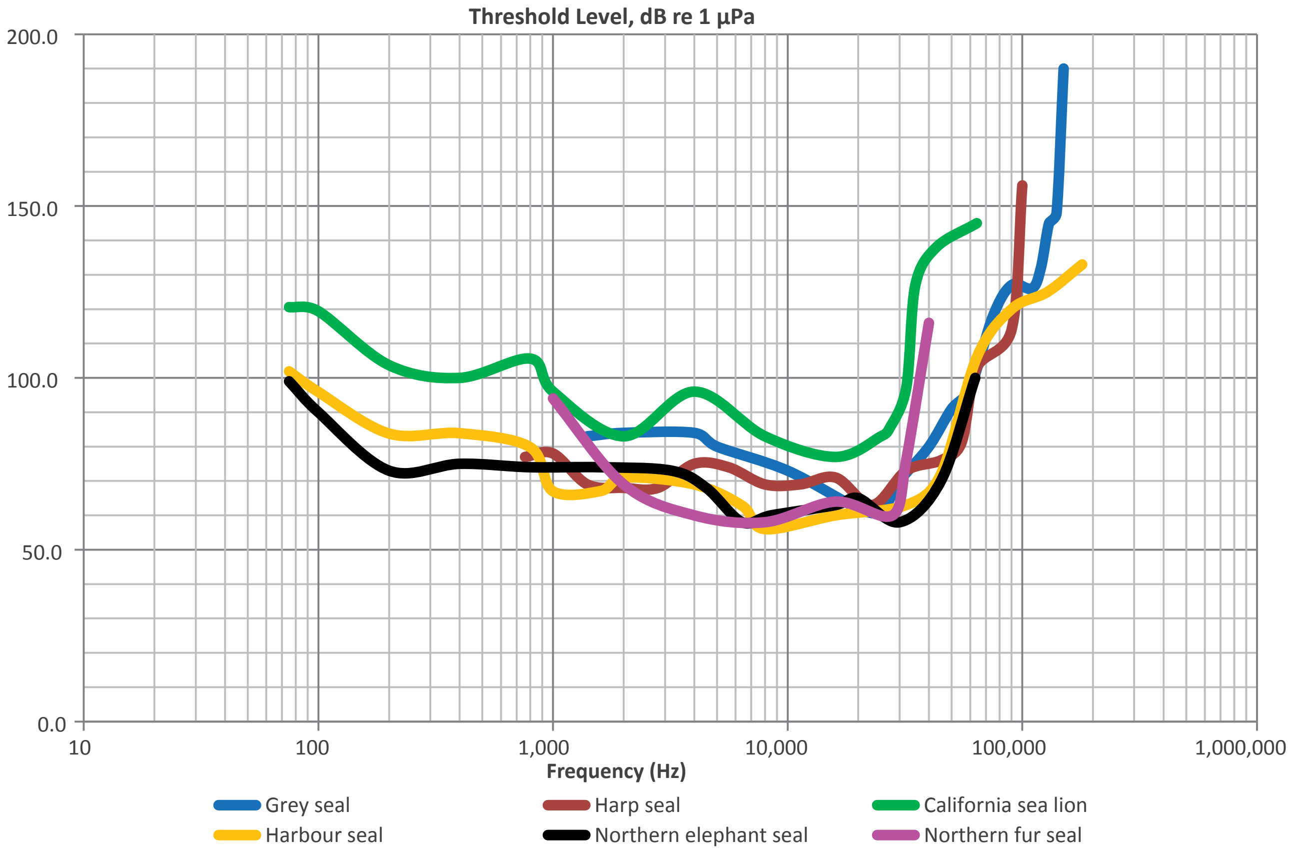
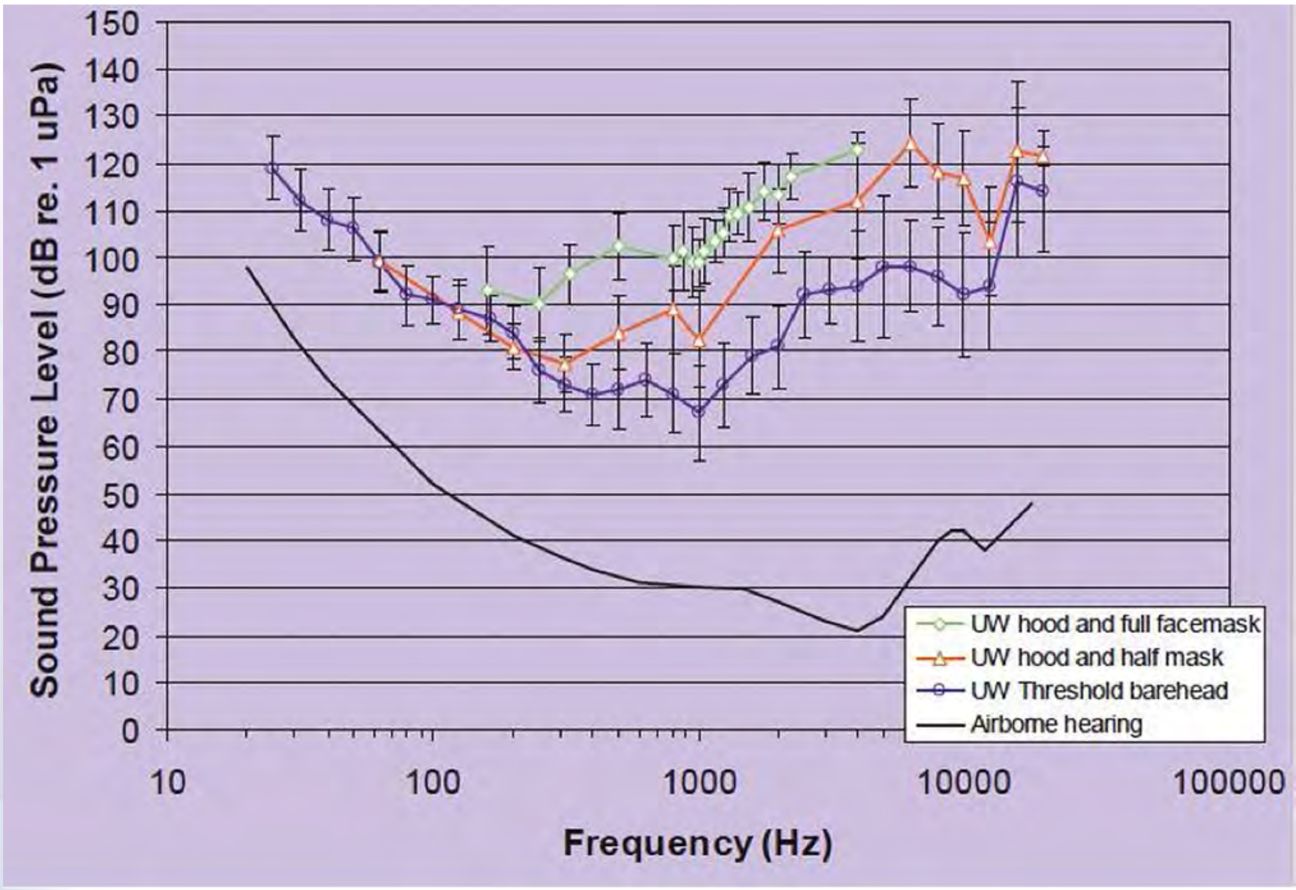


Figure 15.4c: Underwater hearing thresholds of human divers (Parvin, 2005)



15.4.2.6. Fish

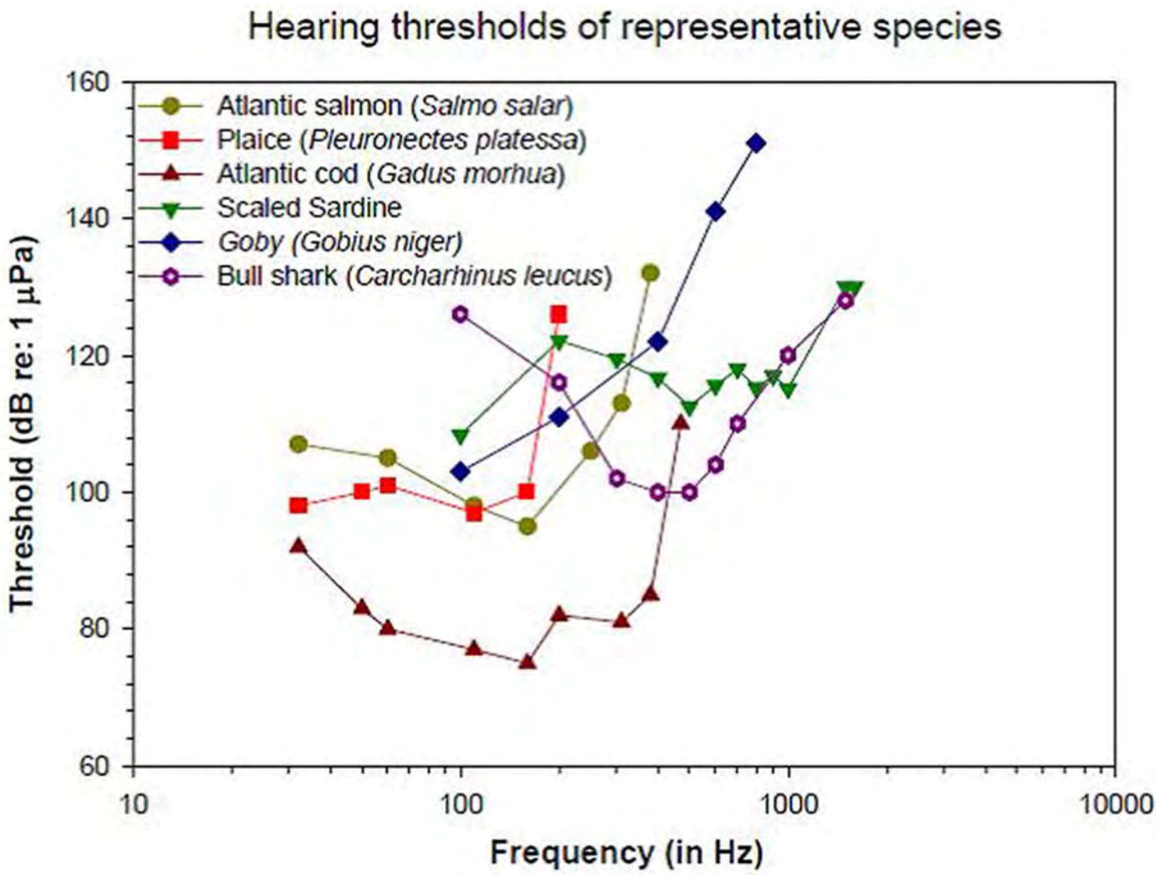
Fish have an inner ear similar to mammals, but lack an outer ear. Hence there is no mechanism for external sound pressure to be directly transmitted to the inner ear, and fish hearing depends on the particular anatomy of the fish as to how efficiently an external sound is transmitted to the inner ear. This results in a wide variety of hearing capabilities between species of fish. Nedwell et al (2006) have broadly split the hearing abilities of fish into three groups of low, medium and high hearing sensitivity. Differences are a result of the anatomy of the fish, including whether it has a swimbladder (a gaseous structure that helps the fish stay at a constant depth) and whether the swimbladder is mechanically coupled to the inner ear of the fish (Nedwell et al, 2004). The hearing thresholds of several "hearing generalist" fish species are shown in **Figure 15.4d**.

Two main modes of "hearing" occur in fish. The stimulation route common to all fish species is known as the "direct" route. In this stimulation mode, acoustic particle motion or hydrodynamic (water) motion accelerates hair cells, including the otoliths (small particles in the inner ear of fish which are sensitive to movement and help balance the fish) and hair cells in the lateral lines of the fish (receptors on the body of the fish that detect close-range water movement) (Hastings & Popper, 2005).

This mode of hearing is inherently directional. Sound pressure as such does not play a direct role (instead, acceleration is sensed, either directly from water movement or indirectly via the vibration of the swimbladder when exposed to an external pressure wave). Species that only have this hearing mechanism are called hearing "generalists".

Fish with swimbladders generally have increased sensitivity of hearing, since the gas-filled cavity of the swimbladder expands and contracts with applied pressure, acting as an acoustic pressure-to-motion transducer and setting up internal vibrations within the fish's body which can be detected by the otoliths in addition to "direct" sensing of the water movement. Some species with a swimbladder have an anatomical adaptation that renders them directly sensitive to sound pressure. In these "hearing specialists," the swimbladder is efficiently coupled mechanically to the fluid systems of the ear, and thus pressure fluctuations in the swimbladder may be detected directly by the otoliths. The hearing specialists are particularly sensitive to sound, with best thresholds in the region of 60 dB re 1 µPa, and hear in a relatively wide frequency range (<1003,000 Hz), with best sensitivity occurring between 200 Hz and 1 kHz .

Figure 15.4d: Hearing thresholds of several "hearing generalist" fish species, adapted from Hastings and Popper (2005).



In general, species without a swimbladder have low hearing sensitivity and will only be sensitive to nearby sound sources where water motion is significant. Examples of such species include flat fish such as the Plaice (*Pleruronectes platessa*) and Dab (*Limanda limanda*).

Species possessing a swimbladder but without specific hearing specialisation have medium sensitivity, e.g. Cod (*Gadus morhua).* These species "hear" through a combination of particle movement and pressure (indirectly sensed via the swimbladder).

Species with a hearing specialisation and thus high hearing sensitivity include the Herring (*Clupea herringus*) and Sprat (*Sprattus sprattus*). These species can "hear" sound pressure directly.

The majority of research into hearing capabilities of fish has been done on northern hemisphere species, and few (if any) studies have been undertaken on species likely to be found in Spencer Gulf. Hence it is necessary to estimate the likely hearing sensitivity of species relevant to this Project based on the known anatomical characteristics of these species.

With regard to the important fish species present in Upper Spencer Gulf, the Snapper, Whiting and Yellowfish, all these species have swimbladders, but are not known to have efficient coupling between the inner ear and the swimbladder. Hence these species are expected to have medium hearing sensitivity, similar to the Cod audiogram presented in **Figure 15.4d.**

15.4.2.7. Sharks

Sharks are mainly sensitive to low-frequency (below 1 kHz) sound (Hastings & Popper, 2005) although sharks are known to be highly sensitive to particle motion via their lateral lines. Shark hearing extends down to "infrasonic" frequencies (below the normal lower threshold of human hearing of 20 Hz), although it is unclear how much of this relates to perception of pressure or perception of particle motion.

15.4.2.8. Cephalopods

Very few studies have been completed on Cephalopod hearing. Although it has been known that Cephalopods can perceive low-frequencies, the mechanism of perception has been shown to be not direct detection of sound pressure but instead perception of particle velocity (Mooney et al. 2010). Mooney et al, (2012) present a useful summary of the current (as of 2012) status of the available research in the literature.

A study by Hu et al (2009) demonstrated that Cephalopods (Octopus and Squid) can perceive sounds up to approximately 1.5 kHz (note that Hu et al tested cephalopods perception over the frequency range 400Hz to 4kHz), and that statocysts (structures used to detect the orientation of the animal, analogous to otoliths in fish) are responsible for perception in the range 400 Hz to 1.5 kHz. Previous studies (Packard et al, 1990, Kaifu et al, 2008 and Mooney et al 2010) have demonstrated that Cephalopods are sensitive to vibration over the frequency range 1-400 Hz, and that the statocycts are responsible for low-frequency hearing via detection of particle velocity, and that Squid are insensitive to very-high frequencies associated with odontocete echolocation (Wilson et al, 2007).

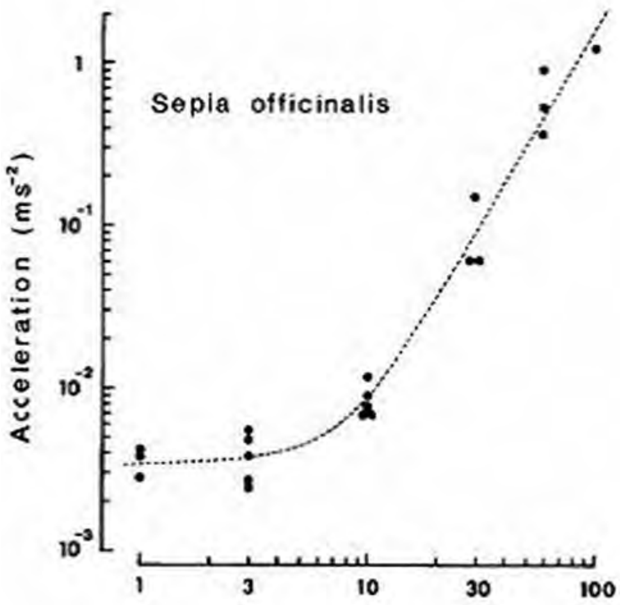
Unfortunately, no study has successfully separated the sound pressure and particle velocity components to demonstrate conclusively whether cephalopods can actually "hear" via pressure perception or whether they are only sensitive to particle velocity (Mooney et al, 2012).

Studies of common Cuttlefish (*Sepia officinalis*) (Packard et al, 1990) suggested that cephalopod perception thresholds are most sensitive below 100 Hz, although the presented values for the perception threshold are likely higher than the true threshold values due to background noise in the test environment (refer to **Figure 15.4e**) – data for octopus from Kaifu et al (2008) shows perception thresholds two orders of magnitude lower under better experimental conditions (refer to **Figure 15.4f**).

Mooney et al (2010) present thresholds for the Longfin Squid (*Loligo pealeii)* over the frequency range 50 Hz to 400 Hz, which show thresholds as low as 110 dB at 1 µPa in this frequency range. These thresholds are shown in **Figure 15.4g**.

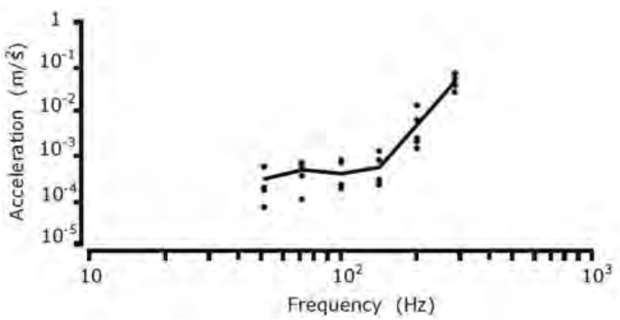
Above 400Hz, thresholds are relatively high (generally 130dB at 1µPa or higher) across the frequency range 400Hz – 1.5kHz. The relative insensitivity to sound in this frequency range compared to "hearing-specialist" fish is theorised to be because Cephalopods lack gas-filled structures like the swimbladder that respond to pressure waves. Hearing thresholds of Cuttlefish and squid are shown in **Figure 15.4h**.

Figure 15.4e: Low-Frequency Perception Thresholds of Cuttlefish (*Sepia officinalis*) (from Packard et al 1990)



Note thresholds are measured in acceleration (m/s²) not sound pressure level (dB re 1 µPa) – data is likely affected by the high background noise in the test environment.

Figure 15.4f: Low-Frequency Perception Thresholds of Octopus (*Octopus ocellatus*) (from Kaifu et al 2008)



Note thresholds are measured in acceleration (m/s²) not sound pressure level (dB re 1 µPa).

Figure 15.4g: Low-Frequency Perception Thresholds of Longfin Squid *Loligo pealeii* (from Mooney et al 2010) (black line indicates average threshold)

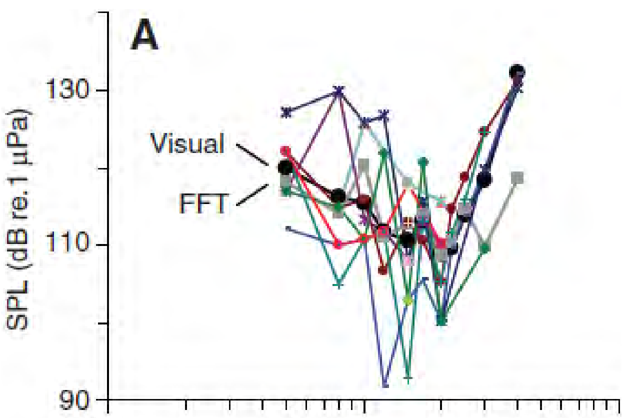
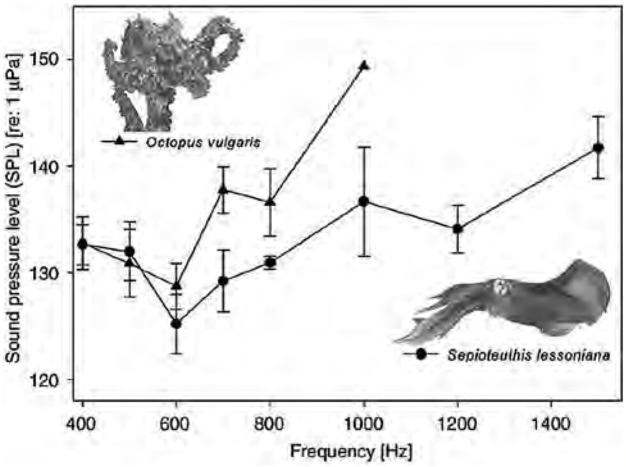


Figure 15.4h: Hearing thresholds of Cuttlefish and Squid, from Hu et al (2009)



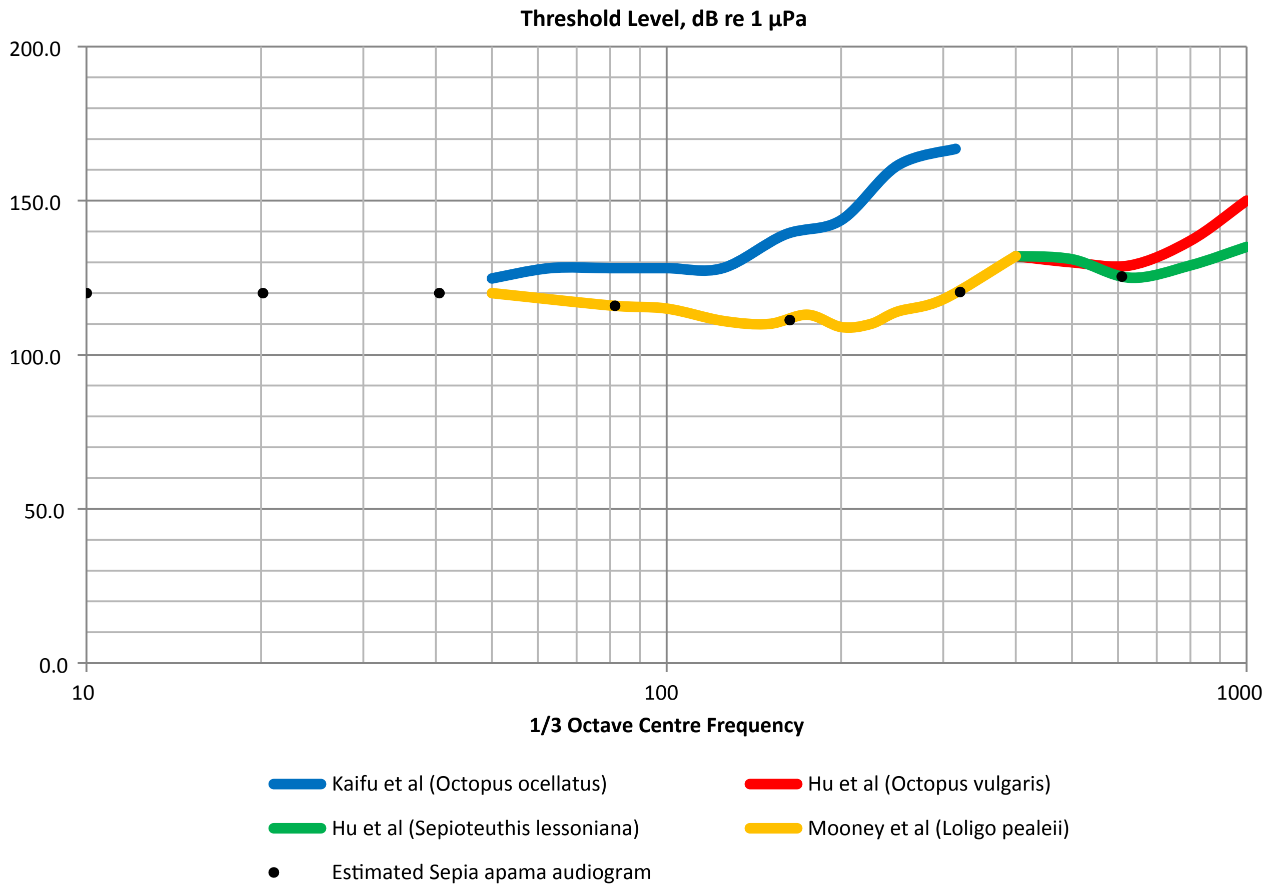
The single species of Squid studied was more sensitive to sound than the single octopus species studied, and was sensitive over a wider frequency range. Hu et al (2009) suggested that the increased sensitivity of squid may be due to this adaptation to different habitats - the Squid occurs in more open reef waters with fewer opportunities for hiding; whereas the Octopus is more commonly found in coastal water with better light and hiding places. Hence, the Squid likely relies on acoustic detection more than the octopus.

Although no studies on the Giant Australian Cuttlefish (*Sepia apama*) are available in the literature, based on the published data for other Cuttlefish (e.g. *Sepia officianalis*) at low-frequency, it is considered more appropriate to use the (more conservative) *Sepioteuthis lessoniana* (reef squid) hearing thresholds presented in Hu et al (2009) to model the hearing of *Sepia apama*, because of the similar habitat and lifestyle of the Giant Australian Cuttlefish to the Reef Squid (Aitken et al, 2004).

An approximate audiogram for *Sepia apama* has been assumed for the purposes of this study based on the hearing thresholds of Hu et al (2009) for *Sepioteuthis lessoniana* above 400Hz, and the hearing thresholds from Mooney et al (2010) for *Loligo pealeii* below 400Hz. Audiograms of cephalopod species, and estimated audiogram of *Sepia apama* are given in **Figure 15.4i**.

Below 50Hz, data in the literature is not available, and a constant threshold of 120dB at 1 µPa has been assumed (i.e. assuming hearing sensitivity below 50Hz is the same as at 50Hz). This is likely a conservative assumption.

Figure 15.4i: Audiograms of Cephalopod species, and estimated audiogram of *Sepia apama*



15.4.2.9. Crustaceans

Hearing capabilities of Crustaceans are similar to those of Cephalopods; both groups lack a gas-filled structure such as the swimbladder and are likely to be only sensitive to particle motion (Lovell, 2005) which is detected via the statocyst.

The one species of Prawn studied in the literature was sensitive to particle motion over the frequency range 100Hz to 3kHz; Hearing thresholds were in the range 105130 dB at 1 µPa. An audiogram of prawn *Palaemon serratus* is given in **Figure 15.4j**.

Due to the similar hearing characteristics of crustaceans to Cephalopods, and the lack of extensive research into their sensitivity to noise, both groups will be assessed together for damage criteria.

15.4.3. Noise Thresholds

A detailed discussion on noise thresholds for species is provided in **Appendix L.1** and is summarised below in **Table 15.4b**.

Figure 15.4j: Audiogram of Prawn *Palaemon serratus*, adapted from Lovell et al (2005)

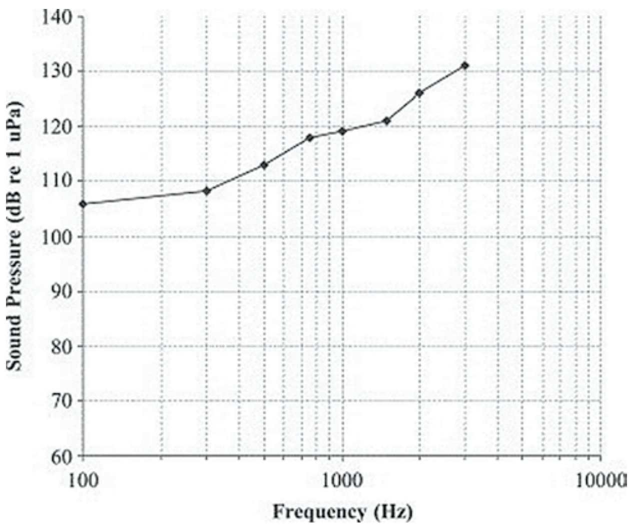


Table 15.4b: Summary of Noise Thresholds for Species

Criterion	Species	Sound Pressure dB at 1 μPa	Sound Exposure Level dB at 1 $\mu Pa^2 \cdot s$
50% Mortality (all sizes)	Fish		210dB
Serious Physical Injury	Marine Mammals	$240dB_{peak}$	
	Fish		195dB
Permanent Hearing Damage	All species	$130dB_{ht}$	$135dB_{ht}$
	Whales –Baleen	$230dB_{peak}$	$198dB(M_{lf})$ (impulsive) $215dB(M_{lf})$ (continuous)
	Whales – Toothed	$230dB_{peak}$	$198dB(M_{mf})$ (impulsive) $215dB(M_{mf})$ (continuous)
	Pinnipeds	$218dB_{peak}$	$186dB(M_{pw})$ (impulsive) $203dB(M_{pw})$ (continuous)
	Cephalopods		178dB
	Humans	212 dB	
Temporary Hearing Damage	Whales –Baleen	$224dB_{peak}$ $160dB_{rms}$ (continuous)	$183dB(M_{lf})$ (impulsive)
	Whales – Toothed	$224dB_{peak}$ $160dB_{rms}$ (continuous)	$183dB(M_{mf})$ (impulsive)
	Pinnipeds	$212dB_{peak}$ $190dB_{rms}$ (continuous)	$171dB(M_{pw})$ (impulsive)
	Cephalopods		163dB
	Humans	190dB (impulsive) 167dB (continuous)	
Disturbance – Strong (~90% avoidance)	All species	$90dB_{ht}$	
	Marine Mammals	$160dB_{rms}$ (impulsive) $120dB_{rms}$ (continuous)	
	Fish	140-160dBpeak (impulsive)	
	Cephalopods	165 dB_{rms}	
	Humans	145-155dB_{rms} (frequency-dependent)	
Masking	Whales – Toothed and Baleen	$115dB_{rms}$	
Detection	Cephalopods	130dB	

15.5. Potential Impacts

15.5.1. Noise Sources

The significant noise sources associated with construction and operation of the proposed bulk commodities export facility (BCEF) are piling noise during construction and vessel noise during both construction and operation of the Project.

These noise sources are discussed in greater detail below.

15.5.1.1. Piling

Pile driving techniques include impact pile driving, where a pile is hammered into the ground by a repeated application of a sudden force, and vibro-driving, where rotating eccentric weights create an alternating force on the pile. Depending on the ground conditions, a socket may need to be drilled before the pile is driven to the necessary depth.

Impact piling will be the main proposed construction methodology for the offshore construction works (Refer to **Chapter 2, Project Description**).

At this stage of assessment, the piling rig is likely to be a IHC S280 rig, which is capable of delivering a maximum blow energy of 280kJ at a rate of 45 impacts per minute (IHC Merwede, n.d.(a)), although final selection of the equipment will depend on the detailed design and geotechnical investigations.

The energy associated with each impact for large-diameter piling may be approximately equivalent to the energy from an explosion of eight kilograms (kg) TNT, with piling impacts occurring as frequently as every one to two seconds. The duration of piling activity depends on the depth of the pile and the strength of the rock, but can involve hundreds or even thousands of pile impacts.

Piling noise is generally more tonal than seismic airgun or explosive waveforms, and may, in extreme cases, cause damage due to resonance effects on underwater life, such as by exciting the resonant frequency in gaseous areas – such as the 25 Hz resonant frequency of the human lung (Nedwell et al, 2007b).

The waveform from a piling impact involves reflection and reverberation effects, including resonance of the pile as it is struck, and secondary noise generation from the seafloor by vibration travelling down the pile. Some piling methods cause additional secondary noise pulses from the piling hammer "bouncing" on the pile head. Typical piling time history data and secondary pile 'bounces' are shown in **Figure 15.5a**.

The dominant frequency range is low-frequency (between 100 Hz and 1 kHz) (Finneran, 2002) as demonstrated by the example spectra in **Figures 15.5b** and **c**.

Figure 15.5a: Typical piling time history data, from McCauley et al (2002) showing secondary pile "bounces". The middle and bottom plots are zoomed-in plots of the last piling pulse in the upper plot showing the "bounces" (middle) and the primary impact (bottom).

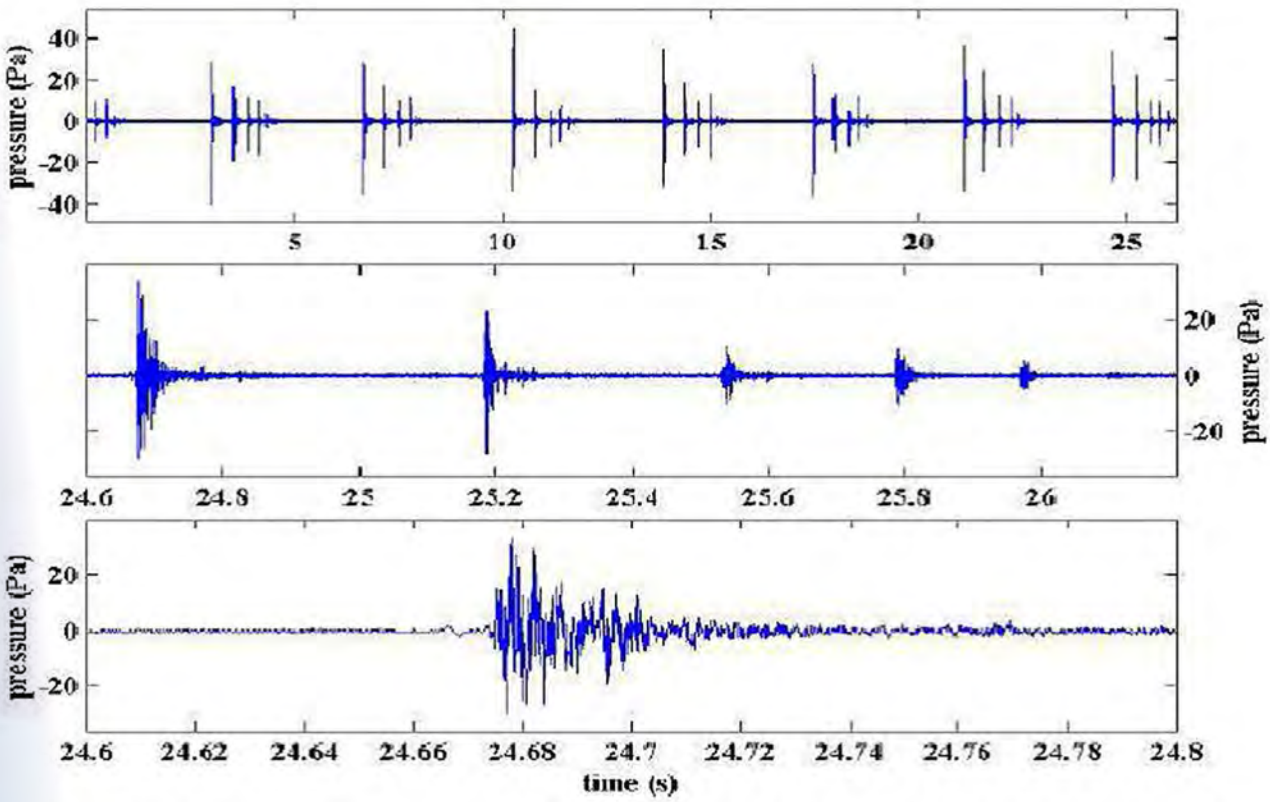


Figure 15.5b: Frequency spectra of impact piling, adapted from McCauley et al (2002) Blue curve is at approximately 300m from source; red curve is at approximately 600m from source.

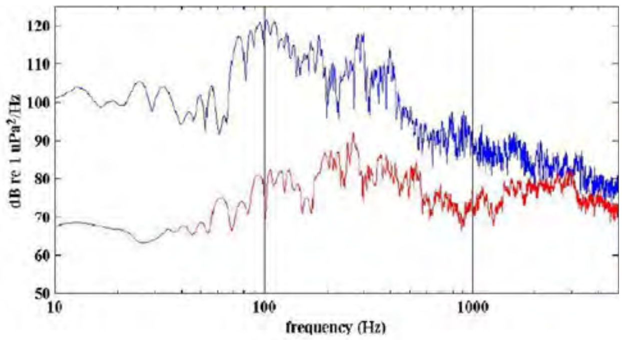


Figure 15.5c: Frequency spectra of impact piling (4.3 m diameter pile) in shallow water, adapted from Nedwell et al (2007b). Blue curve is at approximately 100m from source; green curve is at approximately 10km from source, red curve is background noise at approximately 20km from source.

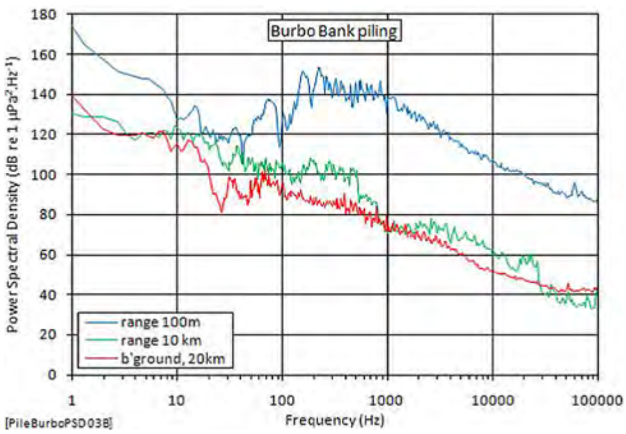
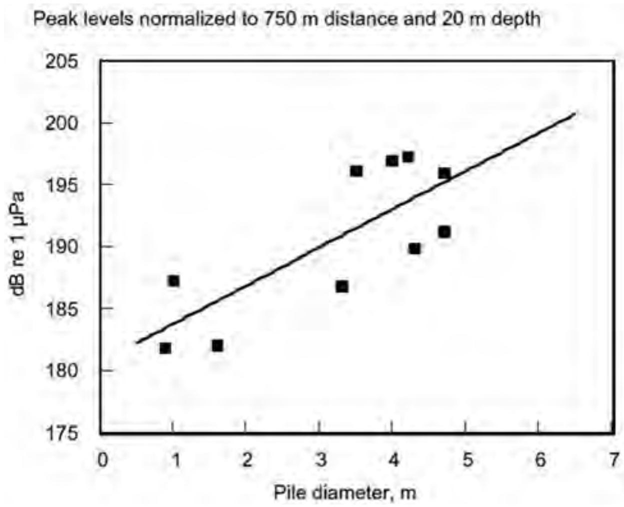


Figure 15.5e: Approximate relationship between pile diameter and peak sound pressure level (normalised to 20 m water depth and 750 m distance from source), from Diederichs et al (2008)



Noise from the impact of piling hammers is directly correlated to the pile diameter (Diederichs et al, 2008), as shown in **Figure 15.5e**.

Peak noise levels from large-diameter (4-5m) piles were recorded at approximately 240-250 dB re 1 µPa (peak) and 200-215 dB re 1 µPa²·s SEL at 1 m (Diederichs et al, 2008). For a 1.2 m maximum diameter pile, such as proposed for the proposed BCEF, this equates to a nominal source level of approximately 230235 dB re 1 µPa at 1 m (peak) and 195200 dB re 1 µPa²·s at 1m (SEL). The piling equipment likely to be used at Port Bonython is similar to equipment used for previous underwater construction works at Webb Dock in the Port of Melbourne. Underwater source measurements of these works by Parnum et al (2009) quoted underwater noise levels that correspond to source levels of 230 dB re 1 µPa at 1m (peak) and 200 dB re 1 µPa²·s at 1m (SEL). These are within the expected range based on the pile diameter.

15.5.1.2. Vessels

Vessel noise is dominated by propeller noise, except when operating at very low speeds where hull radiated noise dominates. During construction of the Port Bonython jetty, propeller noise from workboats or ships underway will likely be the dominant vessel source.

Boats fitted with outboard motors can produce relatively intense sound levels, due to the small propeller size and fast rotation of the propeller, which is not as hydrodynamically efficient and causes higher noise levels due to cavitation. Outboard motors are the most common propulsion type for small boats in Australian waters. Outboard motors produce broadband noise with many strong tonal components, over a frequency range up to 6 kHz. Peak source levels are approximately 150180 dB re 1 µPa at 1m range (Richardson, 1995). A summary of source levels is given in **Table 15.5a**.

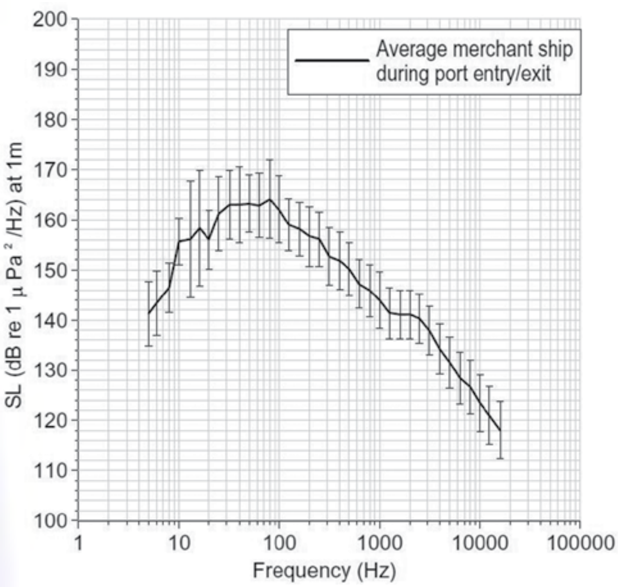
Table 15.5a: Summary of Vessel Source Levels, from Richardson et al. 1995; Dames & Moore 1996; Au and Green 2000, McCauley et al. 2002 and Hallett.

Source	Peak Frequency or Band	Peak Source Level (dB re 1 µPa at 1 m)
Bulk carriers*	50-100 Hz	165-180 dB
64m Rig supply tender*	(broadband)	177 dB
Tug towing barge*	1000-5000 Hz	145-171 dB
8m RIB with two 250 hp outboards*	315-5000 Hz	177-180 dB
Power boat with two 80 hp outboards#	630 Hz	156-175 dB
4.5m inflatable with one 25 hp outboard*	2500-5000 Hz	157-159 dB
Supply vessel	1-500 Hz	182 dB

Once the BCEF is operational, shipping noise from bulk carriers will be the dominant underwater noise source. However, the existing Santos wharf means that the Port Bonython area (and also the Upper Spencer Gulf in general, due to wharfs at Whyalla and Port Pirie) is already exposed to shipping noise, and therefore the additional impacts of shipping are generally due to increased traffic rather than introduction of a new noise source. The exception is that the new wharf is closer to the Cuttlefish aggregation at Black Point and therefore it is relevant to predict the increase in shipping noise that will be received at the Cuttlefish breeding area.

Hallett (2004) presents underwater noise data for merchant ships taken on entry/exit to the Port of Dampier and the Port of Gladstone, shown in **Figure 15.5f**, and gives an average source level of 172dB re 1 µPa at 1m, with dominant frequencies 63-100 Hz. The ships were mainly bulk carriers and hence are likely to be similar to the ships using the new wharf at Port Bonython, which are up to Cape-size 180, 000 tons).

Figure 15.5f: Average source level of bulk carriers entering/exiting port, from Hallett (2004)



The available data indicates that worst-case source levels are approximately the same for small outboard-motor powered boats and for bulk carriers (~180 dB re 1 µPa at 1m), although the frequency of maximum noise generation is different for small/large vessels.

Hence the following source levels will be used for prediction:

- Small work boat 180 dB re 1 µPa at 1 m (dominant frequencies 300 Hz5 kHz)
- Bulk carrier 180 dB re 1 µPa at 1 m (dominant frequencies 50 100 Hz).

15.5.2. Underwater Noise Predictions

15.5.2.1. Source Location

Two source locations were used:

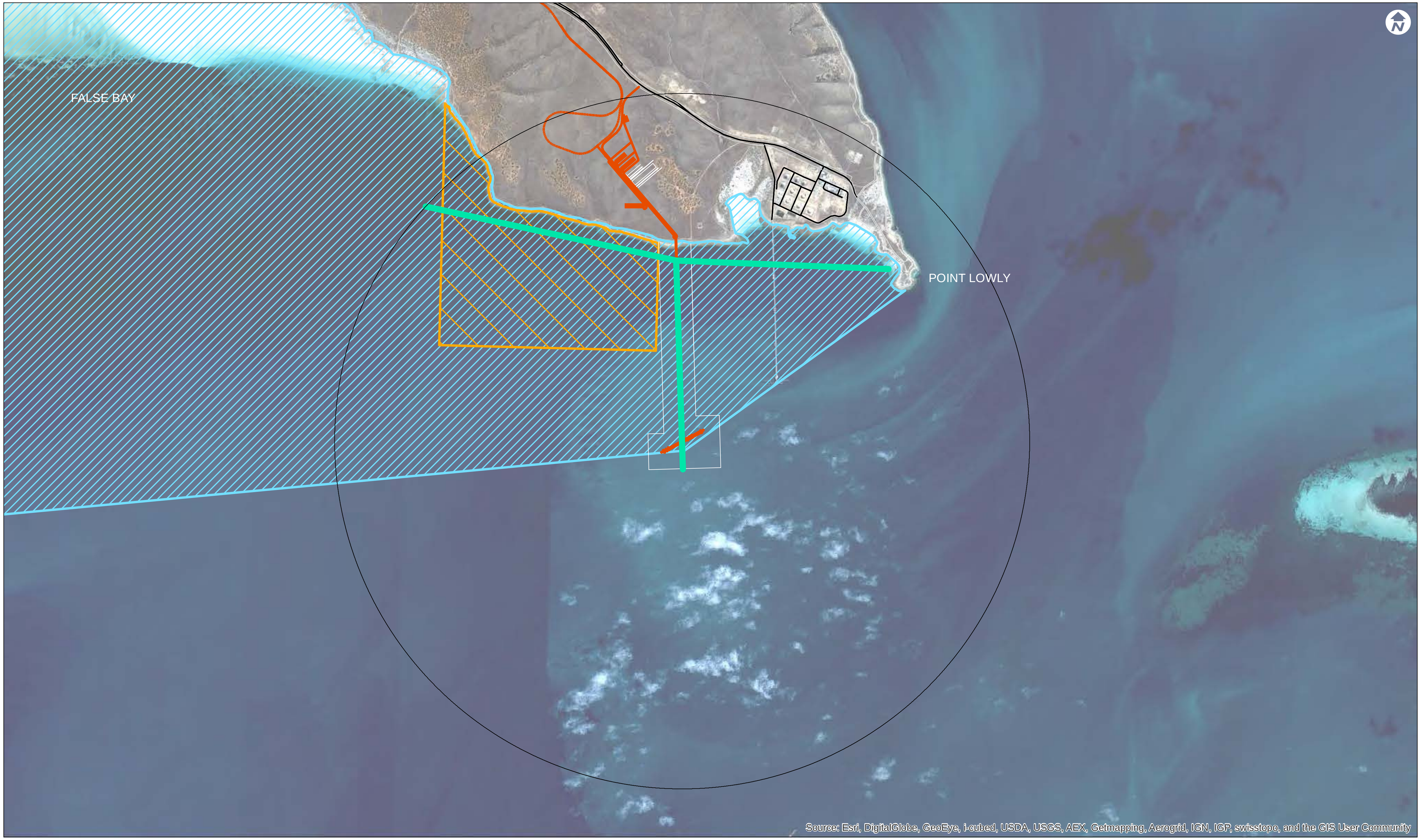
- Inshore source - approximately 400m from shore, corresponding to the likely location of maximum impacts on Cuttlefish from piling for the jetty
- Offshore source - approximately 3000m from shore, corresponding to the furthest pile location for construction noise (and the location of shipping for the finished wharf for operational noise) – this offshore location is the likely location for maximum impacts on marine mammals.

Bathymetry data was obtained from the Geoscience Australia 250m electronic bathymetry grid, plus finer-resolution 1m bathymetry in the vicinity of the wharf.

For the inshore source, three bathymetry traces were used, corresponding to the cardinal compass directions away from shore (East, South, West). The length of each trace was approximately 2.5km (or to shore in the case of the East trace). These are shown in **Figures 15.5g** and **15.5h**.

For the offshore source, ten bathymetry traces were used, corresponding to the eight major compass directions, plus two addition traces to provide additional coverage for the shallow water zone where the Cuttlefish breeding area is located. (i.e. north, north north east, north east, east, south east, south, south west, west, north west, north north west). The length of each trace was approximately 5km (or to shore, in the case of traces that reached the shore before 5km). The offshore source and bathymetry traces are shown in **Figure 15.5i** and **15.5j**.

Figure 15.5g: Location of Inshore Source, showing bathymetry traces used for prediction (green lines), Cuttlefish protected area (blue hatching) and marine sanctuary (yellow hatching)



Port Bonython EIS
Spencer Gulf Port Link

Figure 15.5g - Inshore Noise Impacts

Legend
- Roads
- Transect lines
- Sanctuary zone (USGMP)
- Cuttlefish protection area

ARUP

Spencer Gulf Port Link

1:50,000 (at A3)

0 0.5 1 2
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: Geographic Datum of Australia
Grid: Map Grid of Australia 1994, Zone 53

Figure 15.5g: Location of Inshore Source, showing bathymetry traces used for prediction (green lines), Cuttlefish protected area (blue hatching) and marine sanctuary (yellow hatching)

Figure 15.5h: Bathymetry traces for inshore source (labelled according to bearing from source)

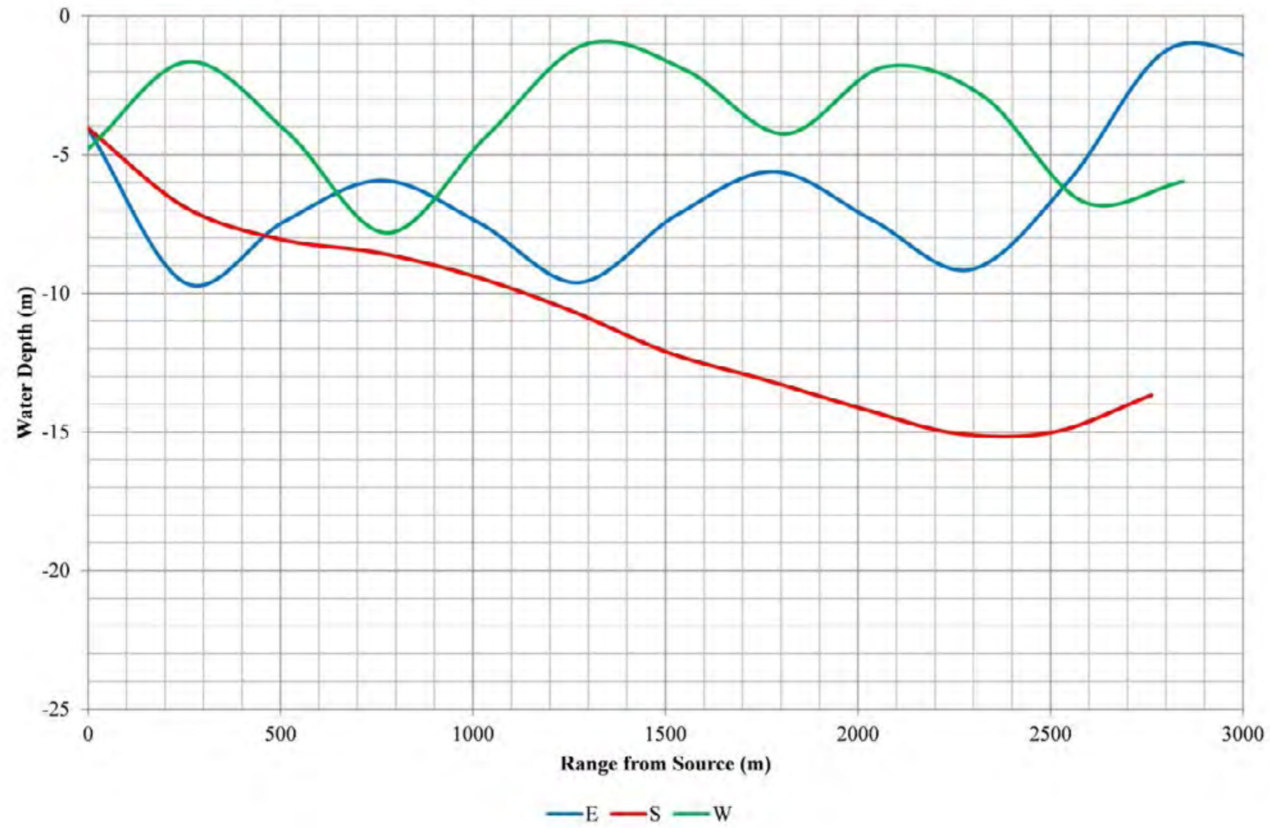


Figure 15.5j: Bathymetry traces for offshore source (labelled according to bearing from source)

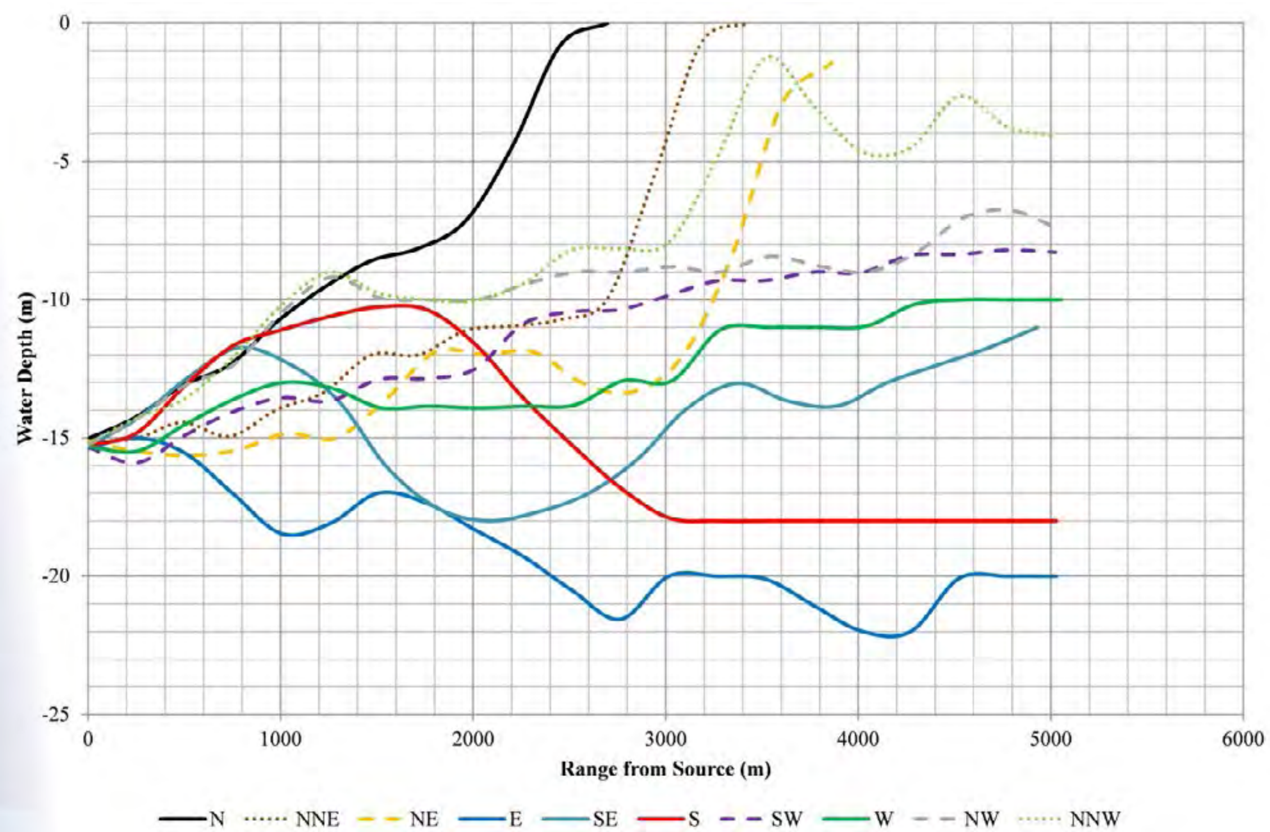
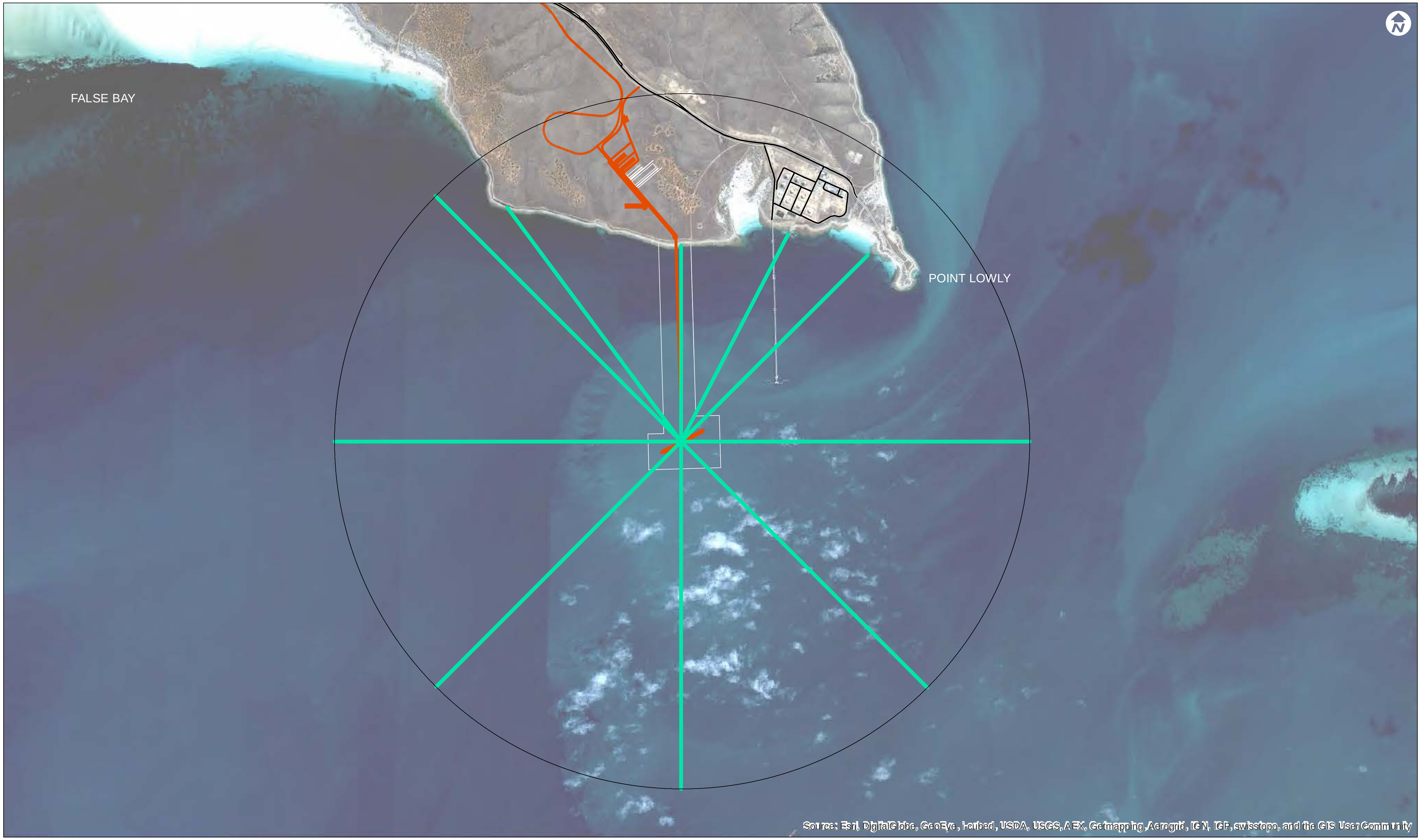


Figure 15.5i: Location of Offshore Source, showing bathymetry traces used for prediction (black lines), Cuttlefish protected area (blue hatching) and marine sanctuary (yellow hatching)



Port Bonython EIS
Spencer Gulf Port Link

Figure 15.5i - Offshore Noise Impacts

Legend

- Roads
- Transect lines

ARUP

Spencer Gulf Port Link

1:50,000 (at A3)

0 0.5 1 2
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: Geographic Datum of Australia
Grid: Map Grid of Australia 1994, Zone 53

Figure 15.5i: Location of Offshore Source, showing bathymetry traces used for prediction (black lines), Cuttlefish protected area (blue hatching) and marine sanctuary (yellow hatching)

15.5.3. Acoustic Properties

The sound speed profile within the water column was calculated using data from the World Ocean Database (US National Oceanographic Data Centre, 2013) for the two nearest measurement points to Port Bonython (Point A: Latitude 32.95° south, Longitude 137.85° east; Point B: Latitude 33.067° south, Longitude 137.733° east), which are both approximately 10km from the Project site. These locations are shown in **Figure 15.5k**. The measurements were taken in May, and therefore the resulting water properties (and hence predictions), given in **Table 15.5b**, are made for the "worst case" winter conditions when both Cuttlefish and Whales are likely to be present at Port Bonython. The resulting sound speed profiles are shown in **Figure 15.5l**.

The temperature, salinity and density profiles are essentially constant with depth, and the change in pressure within the water column is not sufficient to result in a significant change in the sound speed. Hence, assuming constant water properties will result in minimal error.

Water properties of temperature 18.3 Degrees Celsius (°C), density of 1030kg/m³ and sound speed of 1524metres per second (m/s) were used for prediction.

Table 15.5b: Ocean conditions and resulting calculated sound speed profile, Port Bonython

Location	Depth (m)	Temperature (°C)	Salinity (PSU)	Density* (kg/m³)	Sound Speed** (m/s)
A	0	18.2	41.6	1030.3	1523.9
	5	18.3	41.9	1030.7	1524.6
	10	18.4	42.0	1031.0	1525.0
	14	18.4	42.1	1031.2	1525.2
B	0	18.4	40.6	1029.5	1523.3
	5	18.4	40.6	1029.7	1523.4
	10	18.3	40.9	1030.2	1523.6

* Calculated using the Millero et al equation (Millero et al, 1980)
** Calculated using the Del Grosso equation (Del Grosso, 1974)

Figure 15.5l: Sound Speed Profiles used for Port Bonython

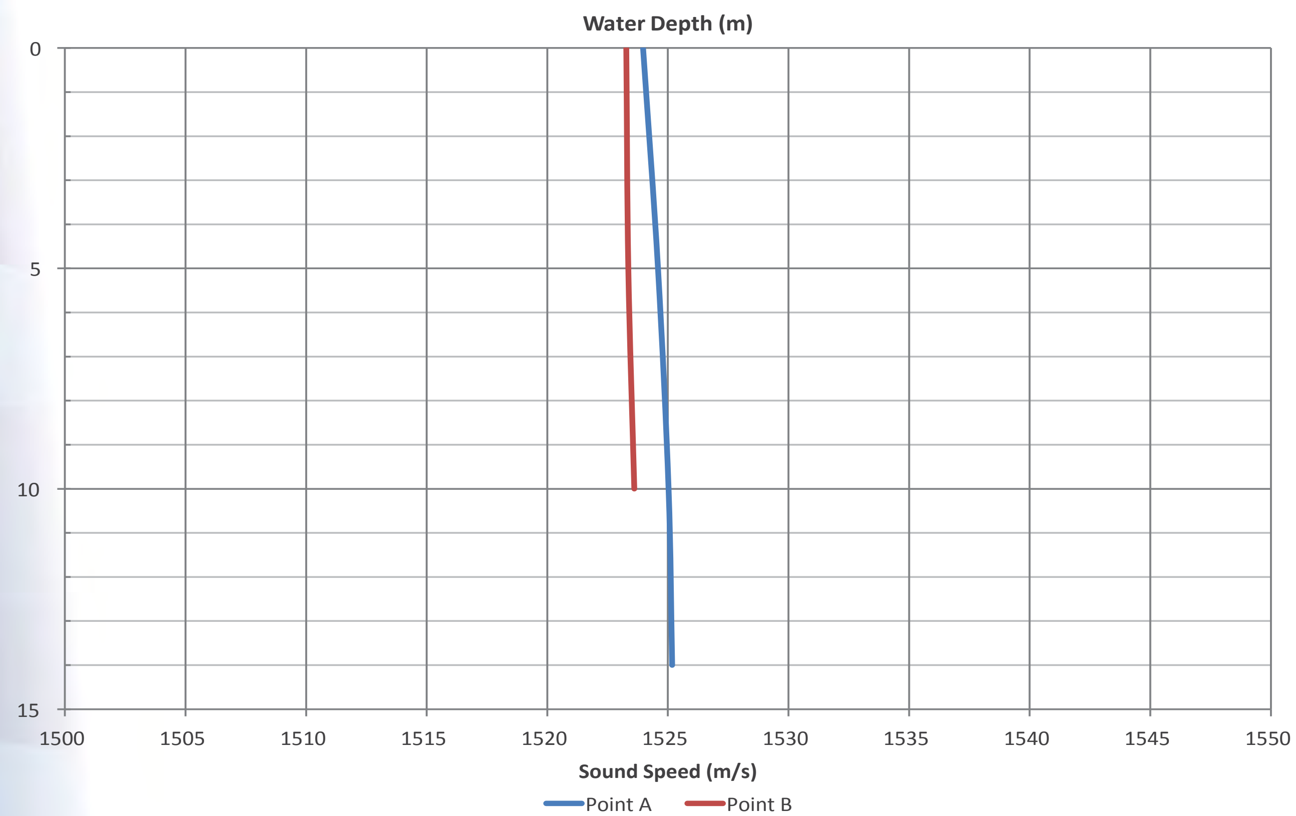


Figure 15.5k: Locations of World Ocean Database measurement points relative to Port Bonython

Port Bonython EIS
Spencer Gulf Port Link

Figure 15.5k -
World Oceans Database
Measurement Points

Legend

Roads

Measurement point locations

ARUP

Spencer Gulf Port Link

1:75,000 (at A3)

0 1 2 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: Geographic Datum of Australia
Grid: Map Grid of Australia 1994, Zone 53

Figure 15.5k: Locations of World Ocean Database measurement points relative to Port Bonython

15.5.4. Predicted Transmission Loss

The underwater transmission loss (TL) was predicted using the RAMGeo model for each bathymetry trace for each source location. The model was calculated for the 1/3 octave bands from 10Hz to 1kHz (i.e. over 21 1/3 octave bands), except for the northern source, where the water depth is too shallow to predict the 10 Hz and 12.5 Hz bands accurately and prediction was made for the frequency range 16 Hz –1 kHz.

The source depth was set as three metres for the inshore (north) source location and 7.5m for the offshore (south) location – i.e. approximately at the mid-point in the water column. This corresponds approximately to noise radiation from the mid-section of a driven pile, or noise radiation from the underwater structure of a vessel (for the south location).

Receiver depth was set at two metres for the northern source (Cuttlefish) and five metres for the southern source (marine mammals), although as the predicted TL plots in **Appendix L.2** show, due to the near-constant sound speed profile, the TL does not vary significantly vertically within the water column at a given distance.

The predicted transmission loss was significantly higher for the north source (in shallow water, which is a less-efficient transmission path for sound). TL was generally greater for low frequencies than high frequencies. This is the inverse of typical underwater conditions where low-frequency propagation is efficient, and occurs because the water depth is not sufficiently deep to efficiently propagate these frequencies.

At high frequencies, the interaction between the sound wave and its reflections from the seafloor and the sea surface leads to several "interference zones" with alternating areas where sound propagation is efficient and areas where sound propagation is inefficient.

Note that since the RAMGeo model predicts the interaction between the water column and the seafloor, transmission loss data includes wave propagation in the seafloor and the rock substrate below. Hence, sometimes the TL plots show sound "escaping" the water column into the seabed (usually for steeper angles of incidence closer to the source. TL plots for each source and each prediction direction are given in **Appendix L.3**

In addition to the graphical plots of transmission loss versus depth and range presented in **Appendix L.3**, RAMGeo also predicts the numerical transmission loss versus range for a line transect at a given receiver depth. This was used to predict the received underwater noise level versus distance for each frequency band for each noise source. The following receiver depths were used for prediction:

- Two metres for the north (inshore) source (approximate representative receiver depth for Cuttlefish)
- Five metres for the south (offshore) source (approximate representative receiver depth for marine mammals).

Example transmission loss plots are shown in **Appendix L.2**.

15.5.5. Source Levels

A source level of 180dB re 1 µPa at one metre was used for shipping noise at the southern source location. The source spectrum was based on the average spectra from Hallett (2004).

A source level of 235dB re 1 µPa at one metre (peak) and 197 dB re 1 µPa²·s at one metre (SEL) was assumed for the impact piling (both north and south locations). The source spectrum was based on the presented spectrum for shallow water piling from Nedwell et al (2007b).

A source level of 200dB re 1 µPa at one metre was assumed for vibropiling (south source location only) based on Parnum et al (2009).

The source levels used for prediction are shown in **Appendix L.3.**

15.5.6. Predicted levels

The following sections show predicted noise levels over each direction from the North and South sources due to construction piling and operational shipping activities. The various thresholds of impact are over-layed over the predicted levels to show the distances at which each impact are expected to occur.

15.5.6.1. Impact Piling Noise- North Source

Predicted underwater levels from piling operation without mitigation measures being applied at the North Source location are shown in **Figure 15.5m** to **15.5r**.

Figure 15.5m: Predicted peak pressure (dB re 1 µPa) from piling – North Source

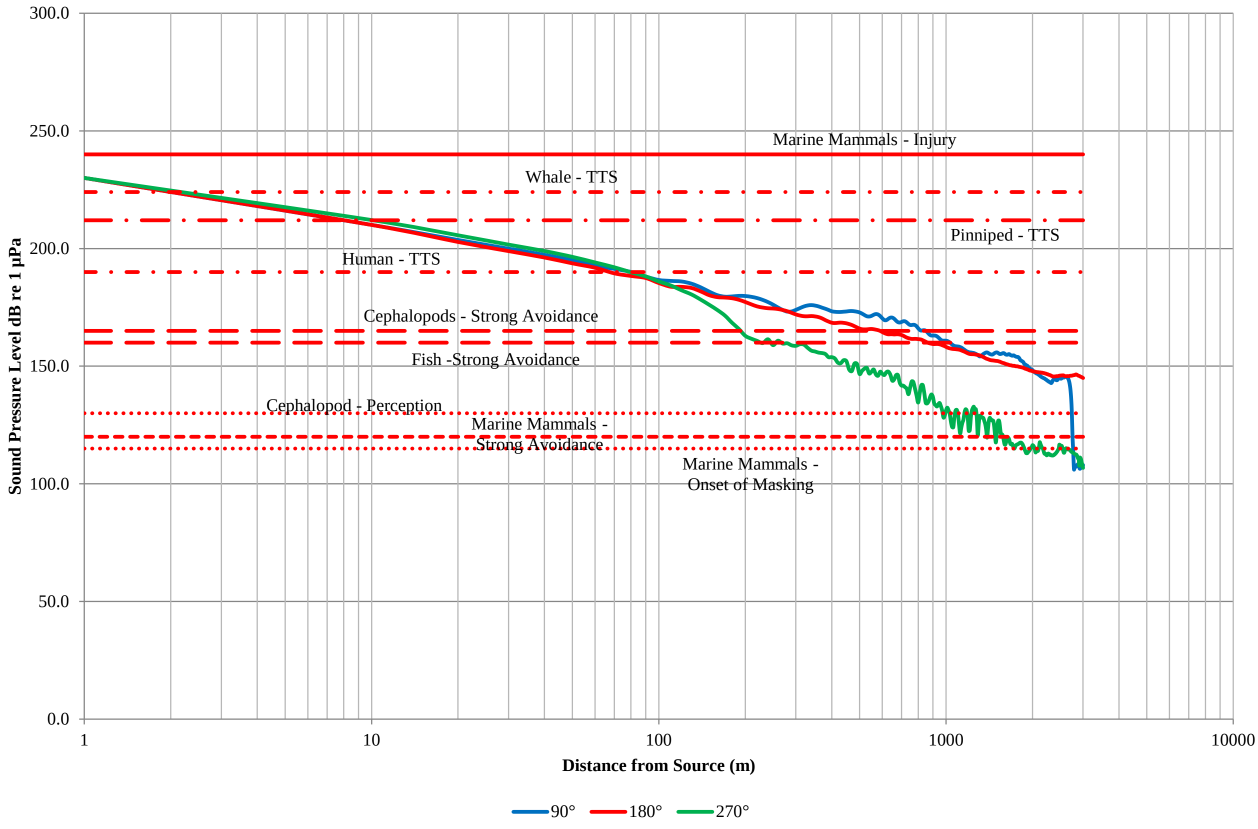


Figure 15.5n: Predicted dBht (*Sepia apama*) peak pressure from piling– North Source

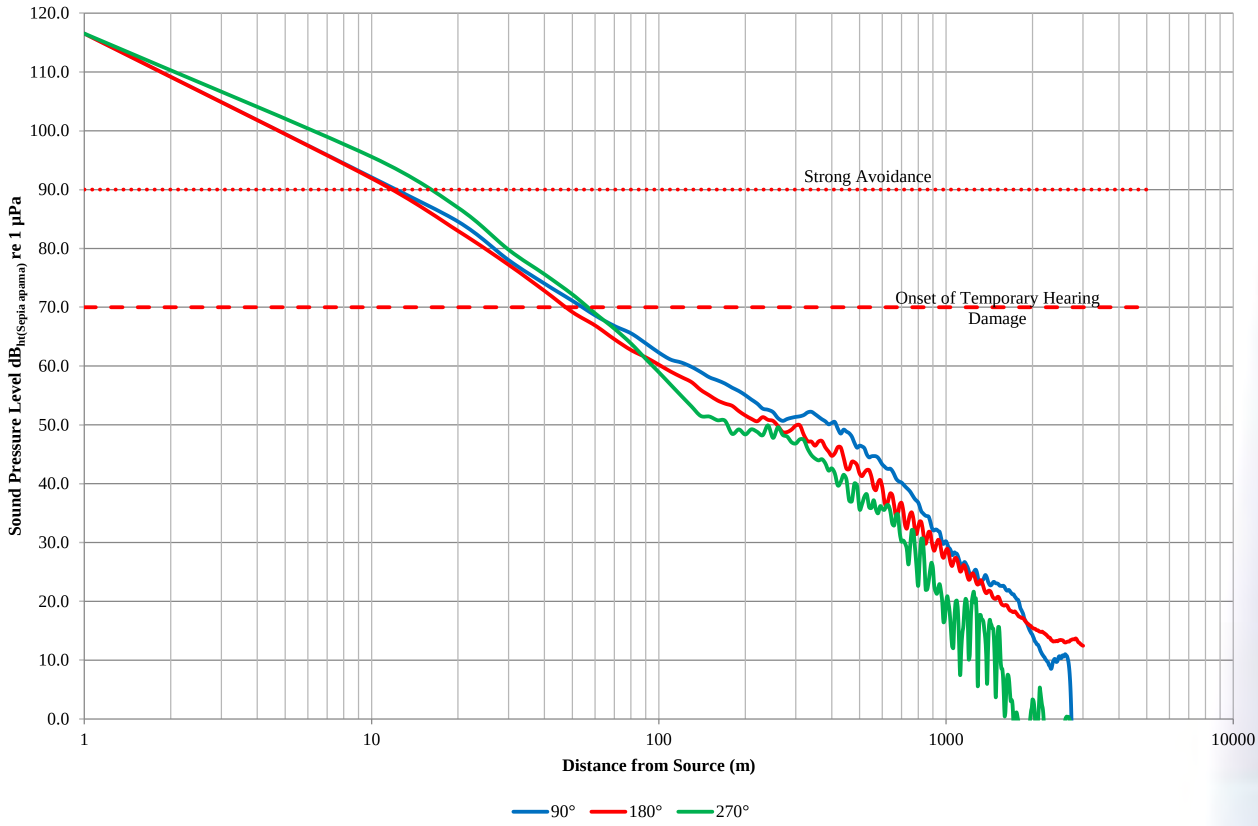


Figure 15.5o: Predicted unweighted sound exposure level (dB re 1 µPa) from piling – North Source

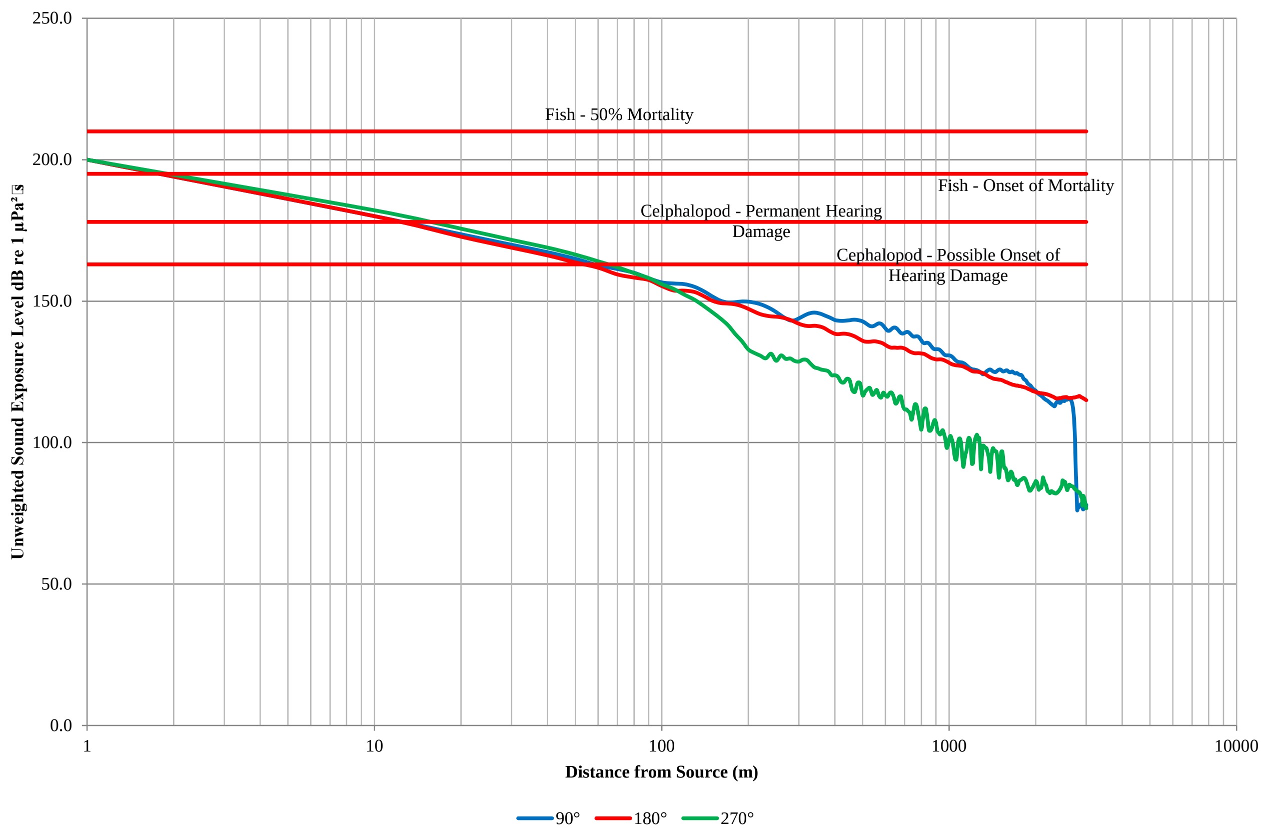


Figure 15.5p: Predicted Mlf-weighted sound exposure level (dB re 1 µPa) from piling – North Source

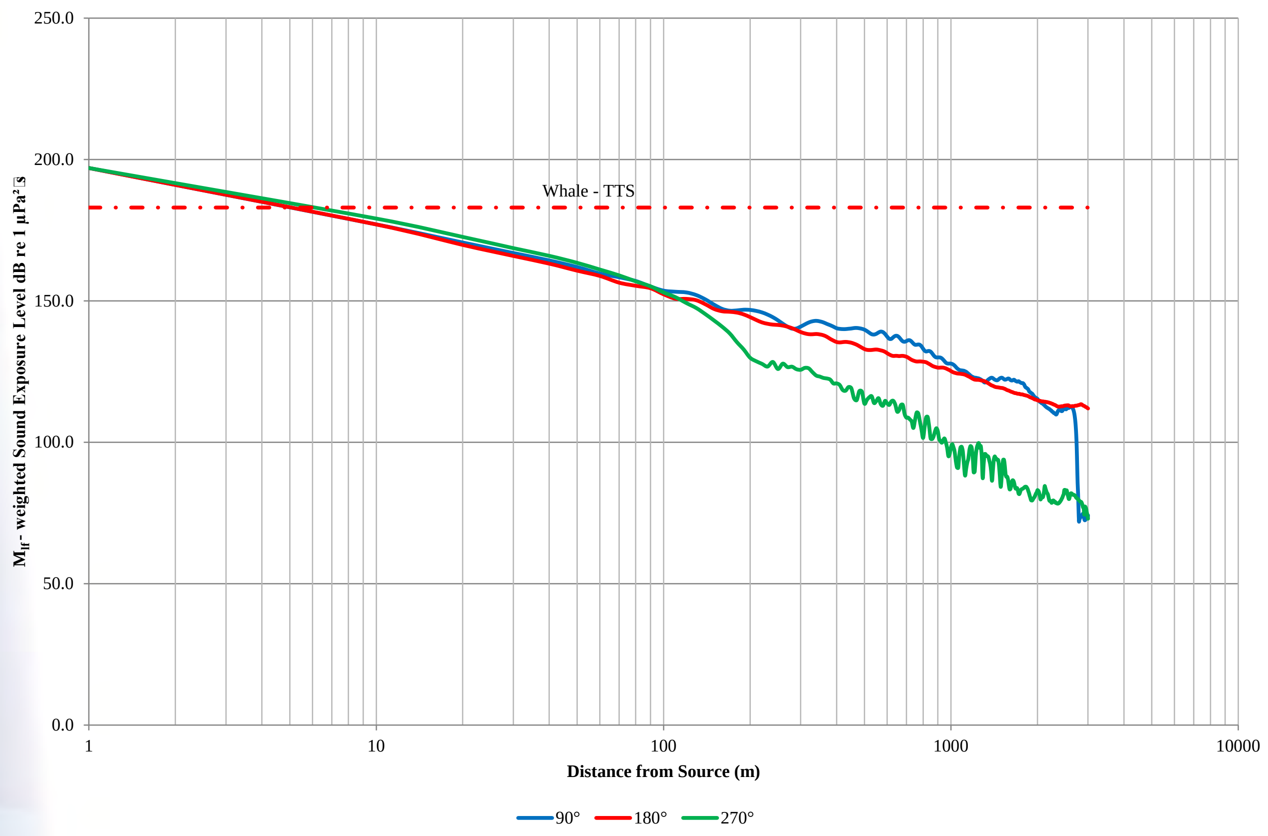


Figure 15.5q: Predicted Mmf-weighted sound exposure level (dB re 1 µPa) from piling – North Source

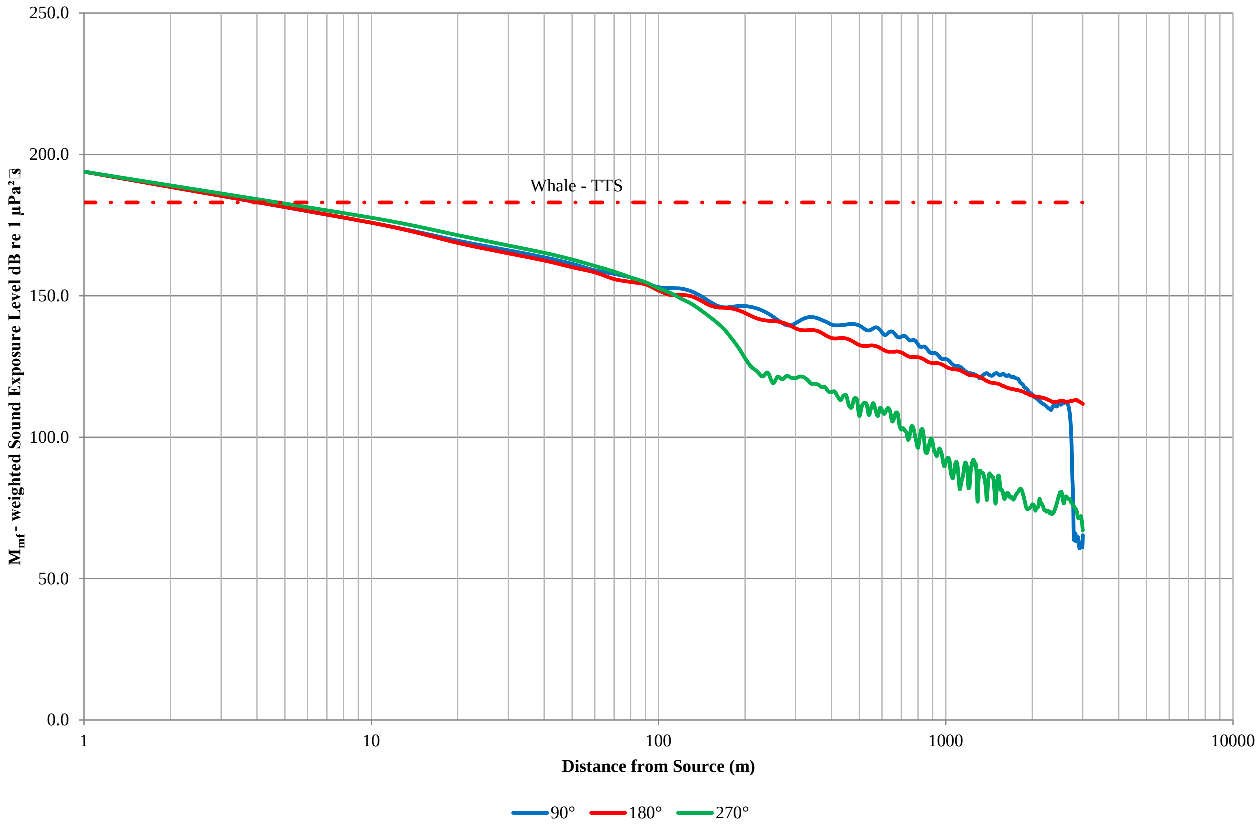
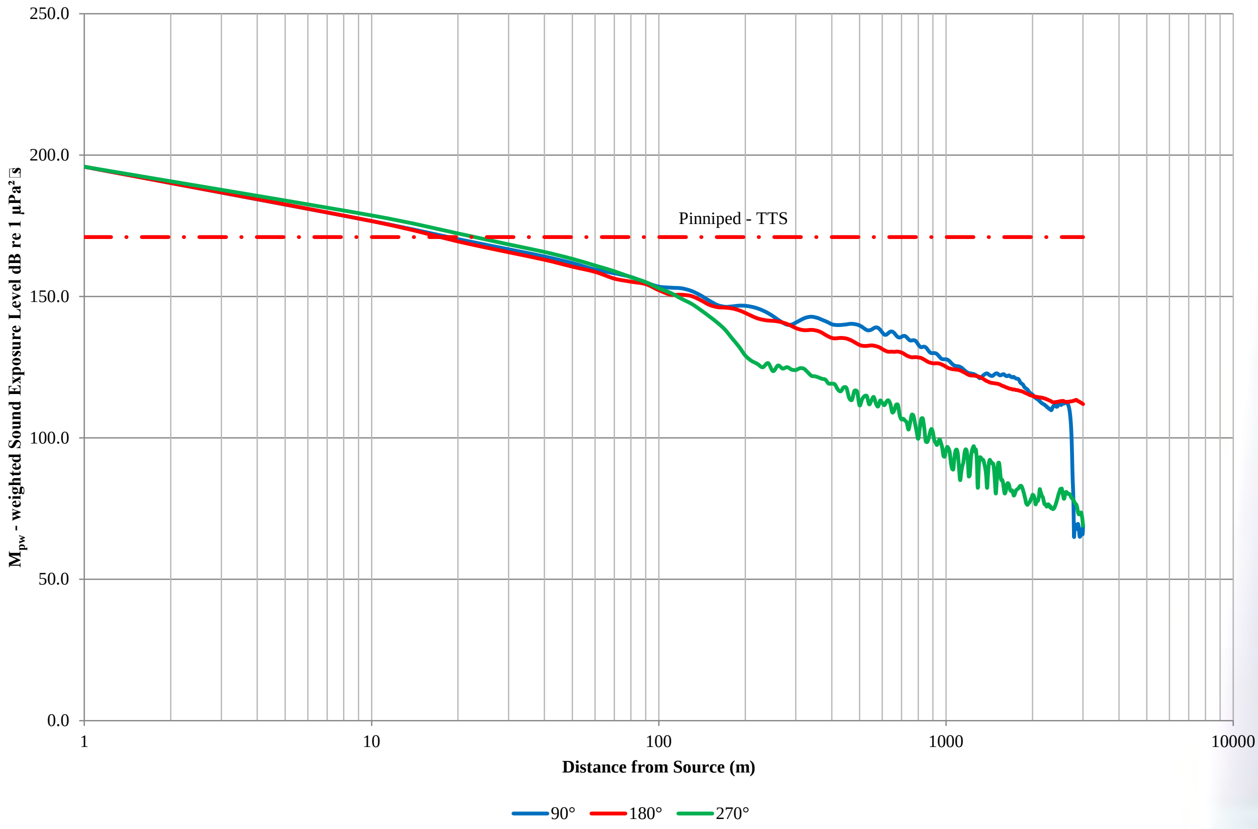


Figure 15.5r: Predicted Mpw-weighted sound exposure level (dB re 1 µPa) from piling – North Source



The following impacts are expected from piling at the north source location should mitigation measures not be applied:

- Fish mortality will likely occur within one to two metres of the piling rig
- Whale temporary hearing damage may occur within approximately ten metres of the piling rig
- Pinniped temporary hearing damage may occur within approximately 20m of the piling rig
- Temporary hearing damage for human divers will occur within approximately 100m of the piling rig
- Auditory damage to cephalopods will likely occur within ten metres of the piling source
- Auditory damage to cephalopods may occur within approximately100m of the piling source
- Avoidance behaviour is expected for fish and cephalopods within 300-1200m of the piling source (depending on seafloor conditions)
- Avoidance behaviour is expected for marine mammals within 3000m of the piling source.

Impacts are predicted to be least in the very shallow water to the west, medium to the south (in the deepening water). Greatest impacts are predicted to the east, where the water is approximately constant depth at 5m - sound propagates more effectively in the slightly-deeper water than to the west, while the constant depth means that sound does not “escape” into deeper water like towards the south.

15.6. Mitigation Measures

Due to the complex propagation of underwater sound waves (particularly in shallow water) there are fewer available techniques to reduce underwater noise impacts than in an airborne noise assessment.

Available techniques are largely restricted to either reducing the source level, or avoiding impacts by making sure that sensitive animals are not in the vicinity of the noise source when it is operational.

Acoustic Scaring Devices

The use of acoustic alarms or small underwater blasts to scare away animals from the construction zone prior to the main construction activity has been suggested (Marine Mammal Commission, 2007) for marine mammals, but other research (Coker & Hollis, 1950) has concluded that explosions have no apparent deterrent effect on fish.

Acoustic harassment devices (i.e. electronic devices emitting high levels of underwater sound at high frequencies, where seals are most sensitive) have been used to deter seals from fish farms by inducing avoidance behaviours, although habituation of animals has been observed (due to the benefits of food outweighing the acoustic disturbance). However, acoustic harassment devices have been observed to be effective at deterring porpoises, although the zone of deterrence may not be sufficient to avoid damage from high-energy pile driving (Hoescle et al, 2011).

Hence scaring blasts are not considered suitable as a control measure for Port Bonython, but acoustic harassment devices may be considered as a possible measure to deter marine mammals from the area during construction.

Nedwell et al (2010) present source levels for four acoustic harassment devices, which produce source levels of approximately130 dB_{ht} at one metre for seals and odontocetes (different devices are available which are tailored for seals or dolphins/porpoises), which suggests that deterrence (levels greater than approximately 90 dB_{ht}) is likely for distances of up to 100m from the harassment device. Hence it may be necessary to use multiple devices arranged as a perimeter around the construction location in order to maintain an effective deterrence function for greater distances.

Due to the requirement to observe observation and shut-down zones around the piling rig (as discussed further in Section 15.6.6) which are significantly larger than the effective zone of acoustic scaring devices, the use of acoustic scaring devices is not recommended as a primary noise mitigation measure. However, scaring devices may be considered as a future management measure during construction if there are difficulties in reliably detecting animals entering the observation zone.

15.6.1. Soft Start

Since damage (generally) increases with closer distance to the source, “ramping up” sound levels can potentially be an effective mitigation measure to avoid animals being suddenly exposed to loud sound levels, e.g. if animals happened to be in the immediate vicinity of the source when it started up.

A gradual increase of sound levels is theorised to allow animals to flee the area without experiencing permanent damage.

The South Australian Underwater Piling Noise Guidelines (DPTI, 2012b) require a soft start of ten minutes at the beginning of piling and after any prolonged (>30 minute) break in piling.

15.6.2. Sound Screening

The US Marine Mammal Commission (2007) also suggested that the use of sound screening measures around stationary sources (such as piling) may be effective in minimising the propagation of the pressure wave. Bubble curtains, blasting mats and damping screens were suggested as potential control measures.

Bubble curtains theoretically may provide a significant reduction benefit by providing an impedance mismatch between the water column and the mixed air/water bubble curtain. Sound propagates less-effectively through this interface. Bubble curtains may also decrease the received sound level by increasing sound scattering – increasing the area affected but decreasing the received level.

Several studies have investigated the effectiveness of bubble curtains for piling noise. Effectiveness of blasting mats and damping screens has not been extensively studied.

Würsig et al (2000) reported on using a bubble curtain to reduce transmitted noise levels from piling in shallow depth water. Effectiveness of the bubble curtain, shown in **Figure 15.6a**, was found to vary depending on bubble size (larger bubbles were less effective as they merged together), and also the orientation of the source barge relative to the receiver (i.e. reflection via the underside of the barge was "short-circuiting" the bubble curtain). Overall reductions were in the range 3-5dB, with best performance in the frequency range 4006400Hz.

Lucke et al (2011) reported reductions generally in the range of approximately 10-15dB due to operation of a bubble curtain to shield porpoises in an enclosure from piling noise, with mean reductions of 14dB for peak pressure and 13dB for SEL.

Porpoises initially exhibited avoidance behaviour from the piling noise (with no bubble curtain), but the avoidance behaviour ceased when the bubble curtain was operating. The bubble curtain appeared to be beneficial in providing masking noise to decrease disturbance as well as reducing the received sound level.

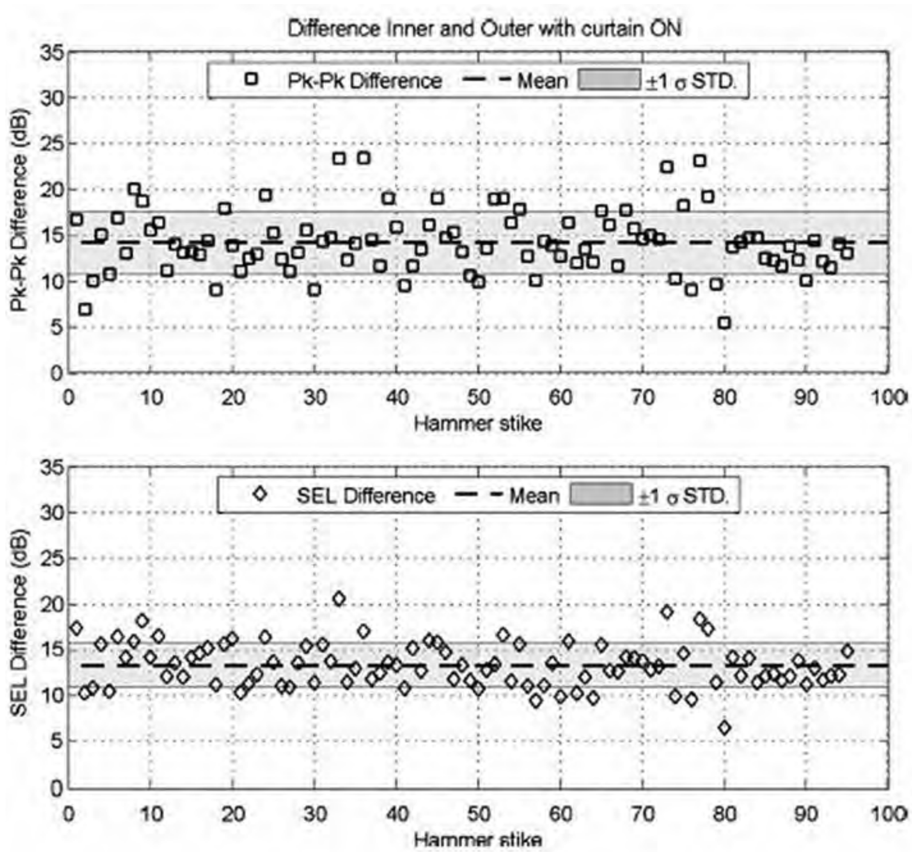
The studies indicate that a properly-designed and configured bubble curtain is able to provide a reduction of approximately10dB or greater in received piling levels.

IHC Merwede supplies a commercially-available pile screen, known as the *Noise Reduction System* (NRS), which consists of a flexible "bellows" sleeve that is placed around the piling rig. The noise reduction is achieved through a combination of a bubble curtain and the impedance mismatch between water and the double-walled "bellows" sleeve. Quoted noise reductions for the NRS are ten dB or greater, which is approximately the same as a well-designed bubble curtain.

The noise predictions show that a properly-implemented bubble curtain (or similar noise screening device, e.g. IHC Merwede *Noise Reduction System* may reduce the size of the zone of impact from piling operations.

Because of tides and depth of water, bubble curtains are likely to be difficult to install and manage effectively at the BCEF.

Figure 15.6a: Effectiveness of bubble curtain (reduction due to bubble curtain) for peak sound levels (top) and SEL (bottom), from Nedwell et al (2010)



Method Substitution

Underwater noise levels from piling operations may be significantly reduced by substituting a non-impulsive pile driver, such as a vibropiling driver, with source levels approximately 30 dB below the equivalent impact piling rig (e.g. the measurements of Parnum et al (2009), which presented results equivalent to an underwater SPL of approximately 200 dB_{rms} at one µPa at one metre). Typical piling durations from Parnum et al (2009) were of the order of five minutes per pile.

Vibropiling may be considered for the offshore piling (from the self-elevating platform), although impact piling may still be required to bring the pile to completion for the last few metres; depending on the precise geological conditions.

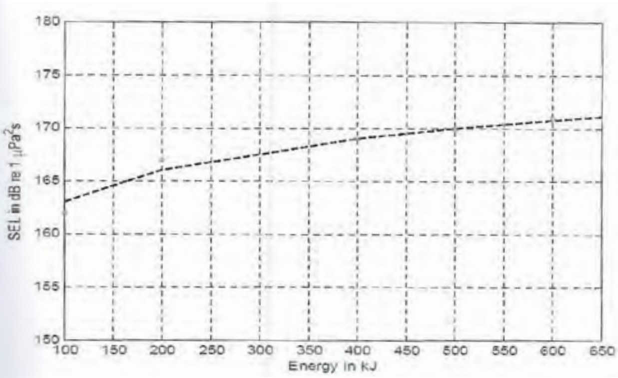
Piling from the cantilever traveller rig used inshore must be done using impact piling.

Hence, vibropiling would not be effective in reducing potential impacts on cuttlefish (which are most significant for the north source). Although vibropiling could be considered as an option for the south source, it is unlikely to be able to completely replace impact piling. Given that the predicted zones of impact from the south source are significantly smaller than the required observation and shut-down zones, and that impact piling would likely still be required, it is not considered reasonable to implement vibropiling as a mitigation measure for the BCEC.

15.6.3. Reduced Impact Energy

The sound level from impact piling is correlated to the amount of energy in the blow (IHC Merwede, n.d.(b)), with an approximate linear relationship between impact energy and acoustic energy (i.e. sound level scales with ~10 log[Energy]).

Figure 15.6b: Approximate relationship between piling impact energy and Sound Exposure Level, from IHC Merwede (n.d. (b))



This indicates that sound levels from piling may be reduced by reducing the impact energy, although at the cost of requiring a greater number of pile impacts to bring the pile to completion.

In cases where the peak pressure (not the SEL) is the governing factor for noise impacts, reducing the impact energy may be an effective way of reducing impacts.

In cases where the SEL is the governing factor for noise impacts, this is not expected to be an effective mitigation technique, because the number of pile impacts to finish the pile will increase and hence the overall noise dose will be approximately the same.

The predicted levels indicate that sound exposure levels are generally controlling impact zones, and therefore adjusting the pile impact energy is unlikely to have a significant benefit.

15.6.4. Safety/Exclusion Zones

It is common to adopt safety zones around the sound source and to monitor for animals entering these zones, shutting down the sound source if necessary if the animal continues to approach the source.

This approach typically relies on detection of animals by trained observers, and hence is most effective for marine mammals, which must periodically come to the surface to breathe. Reliably detecting other animals may be difficult or impossible.

The requirement to visually detect animals means that piling activities must occur during daylight hours.

An alternate approach, using passive acoustic monitoring to detect noise signals from animals has been proposed (Parvin et al, 2007) and is theoretically more effective for detecting marine mammals before they enter the damage zone for piling noise, allowing the activity to be shut down. However, this relies on the ability of the operator to recognise animal signals and thus requires trained operators, and is not yet considered sufficiently reliable to replace visual observation.

The *South Australian Underwater Piling Noise Guidelines* (DPTI, 2012b) set out two safety zones:

» The observation zone (where animals are detected and monitored, and the activity is prepared to be ceased if the animal continues to approach)

» The shut-down zone (where piling shuts down as soon as reasonably practicable if the animal enters this zone).

The size of these zones is determined based on the source emission from the piling activity (based on the SEL from a single pile strike). These safety zones are shown in **Table 15.6a** below.

Table 15.6a: Underwater Piling Noise Guidelines Safety Zones (DPTI, 2012b)

Received Noise Level SEL dB(M) re 1 µPa²·s	Observation Zone	Shut Down Zone
≤ 150 dB at 100m	1km	100m
≤ 150 dB at 300m	1.5km	300m
> 150 dB at 300m	2km	1km

Note that these zones are evaluated for each and every relevant group of marine mammals– i.e. using M_{mf}, M_{lf}, M_{pw} etc. and hence a different safety zone may apply for different groups – e.g. a one kilometre observation zone for pinnipeds, but a two kilometre observation zone for low-frequency cetaceans.

For the north source, the SEL from one strike is approximately 155dB(M) at 100m, and approximately 140 dB(M) at 300 m. Hence the required observation zone is 1.5km and the shut-down zone 300m. For the south source, the SEL from one strike is greater than 150dB(M) at 300m. Hence the required observation zone is 2km and the shut-down zone 1km.

These observation zones may be generalised for all piling locations based on water depth:

- Water depth 0-5m: observation zone 1.5km, shut-down zone 300m
- Water depth >5m: observation zone 2km, shut-down zone 1km.

The required shut down zones are significantly larger than the predicted zone in which damage to marine mammals is predicted to occur and hence no injury is expected to marine mammals if these zones are followed in construction.

15.6.5. Scheduling

Since several of the potentially-affected species are migratory and are only present in Upper Spencer Gulf for part of the year, a simple but very effective mitigation measure is to schedule construction to occur during times when the species are not present.

This measure is recommended to be considered to control impacts on the Giant Australian Cuttlefish, which is difficult to detect via acoustic or visual means without sending in divers, and which is unable to effectively flee the area; hence use of shut down zones is unlikely to be practicable.

This is especially recommended in light of the inconclusive research, lack of an accurate "safe exposure level" for Giant Australian Cuttlefish, and its sensitivity to depletion of breeding stocks. It is proposed that piling activities not occur in the inshore area near the Cuttlefish aggregation area between the months of May to October. Surveys will be undertaken prior to and during the Cuttlefish aggregation season to determine their presence; should the species not be present, piling activities will continue as normal.

Immediate permanent auditory damage to cuttlefish is expected to occur within the following distances:

- Approximately 20m for the north source location
- Approximately 50m for the south source location.

The difficulty is that the safe exposure level for Cuttlefish is not known from the literature; hence it is possible that some auditory damage may occur outside of these zones. The three different criteria proposed give significantly different estimates for the zones of impact:

Using the dB_{ht} approach, the estimated zones of impact (based upon 70 dB_{ht} onset of temporary hearing damage) are:

- Approximately 50m for the north source (approximately 20m with bubble curtain)
- Approximately 300m for the south source (approximately 40m with bubble curtain).

Using the alternate SEL-based criterion of 163 dB re 1 $\mu Pa^2 \cdot s$ results in the following estimated distances:

- Approximately 70m for the north source (approximately 20m with bubble curtain)
- Approximately 400m for the south source (approximately 80m with bubble curtain).

The dB_{ht} and SEL approaches agree closely in the zones of impact. This will be expected, since studies have shown dB_{ht} and SEL to be more accurate predictors of auditory damage than unweighted peak pressure.

In the absence of further research, the most prudent approach will be to schedule in-shore piling activities so that as much piling as possible occurs during months when the Cuttlefish are not resident in the Port Bonython area during the aggregation period, approximately May to October.

The available literature (e.g. Hall and Hanlon 2002) suggests that the breeding zone extends to approximately 130m offshore; hence piling activities greater than approximately 550m offshore from Lowest Astronomical Tide (LAT) are unlikely to cause significant impacts.

Construction should be scheduled so that the piling rig is located beyond greater than approximately 550m offshore for any construction between May and October. If surveys demonstrate that the Cuttlefish is not present during this time, piling activities will continue as normal.

With the application of scheduling as a mitigation measure, it is not considered necessary to install bubble curtains to provide acoustic protection to Cuttlefish.

The shutdown zone required by the *Underwater Piling Noise Guidelines* is significantly larger than the predicted zones of impact on marine mammals. Hence, by implementing the observation and shut-down zones, it is not considered necessary to install bubble curtains to provide acoustic protection to marine mammals.

15.6.6. Monitoring

Underwater noise monitoring will be conducted at the beginning of construction to calibrate the predicted impact zones based on the actual piling rig selected and the precise bathymetry of the piling site.

15.7. Shipping Noise

Avoidance behaviour from marine mammals may occur at distances of approximately 3000m from the vessel. This avoidance behaviour may minimise the chance of injury to animals from collisions with ships.

At distances greater than approximately 1200m, shipping noise will likely be imperceptible for Cuttlefish. Hence, operational impacts on the Cuttlefish breeding area (located approximately 2500m from the loading berth) are likely to be negligible.

The predicted sound pressure level from shipping is shown in **Figure 15.7i** and **15.7j**.

15.8. Summary of Impacts

Piling noise is predicted to have **minor** impacts on fish, with localised fish mortality within the immediate vicinity of the piling rig and behavioural changes (avoidance) expected within approximately 3000m of the piling rig. The commercial fish farms and commercial fishing areas lie further than 3000m from the Port Bonython site, and hence no significant impacts on commercial fishing are expected from construction of the BCEF wharf.

Piling noise is expected to have **negligible** impacts on marine mammals, with hearing damage limited to the immediate vicinity of the piling rig (up to approximately 50m), at which point the management measures (safety zones etc.) require the piling operation to be shut down. Although behavioural changes (avoidance) are expected, these are not considered to have significant long-term impacts since the Upper Spencer Gulf does not lie on a migration route.

Sufficient data is not available to determine what the safe exposure level to underwater noise is for the Giant Australian Cuttlefish and further research is required; however, based on the likely hearing sensitivity of Cuttlefish, there may be some impacts on some areas of Cuttlefish habitat if inshore piling occurs during winter months. Piling noise is expected to have **negligible** impacts on the Giant Australian Cuttlefish however, as inshore piling activities will be scheduled during summer months when the Cuttlefish are not aggregating in the Port Bonython vicinity.

Additional shipping noise impacts associated with operation of the new wharf at Port Bonython are predicted to have **negligible** impacts on the Giant Australian Cuttlefish. Shipping noise is predicted to be below 130 dB re 1 µPa (the approximate hearing threshold of cephalopods) at 1200m from the vessel. The wharf is approximately 2500m from the shallow-water Cuttlefish habitat and hence shipping noise is likely to be imperceptible for the Cuttlefish.

Shipping noise is predicted to have **negligible** impact on marine mammals. There is existing vessel traffic from Port Bonython and the upgrade will result in additional vessels of similar type to the existing vessels. Noise levels from shipping are predicted to cause avoidance behaviour in whales at a distance of approximately 3000m from the vessel, and hence direct physical damage to due collisions between ships and marine mammals are unlikely to occur.

These impacts are summarised in **Table 15.8a**.

Table 15.8a:

Potential Impact	Mitigation	Significance of Impact	Likelihood of Impact	Residual Risk
Impact of piling on fish	Soft starts	Minor	Unlikely	Low
Impacts of piling on marine mammals	Soft starts, safety zones	Negligible	Unlikely	Low
Impacts of piling on Giant Australian Cuttlefish	Soft starts, scheduling outside of breeding season	Moderate-High	Highly Unlikely	Low-Medium
Shipping noise	No mitigation required	Minor	Unlikely	Low
Other construction noise	No mitigation required	Minor	Unlikely	Low

Figure 15.7i: Predicted sound pressure level (dB re 1 µPa) from shipping – South Source

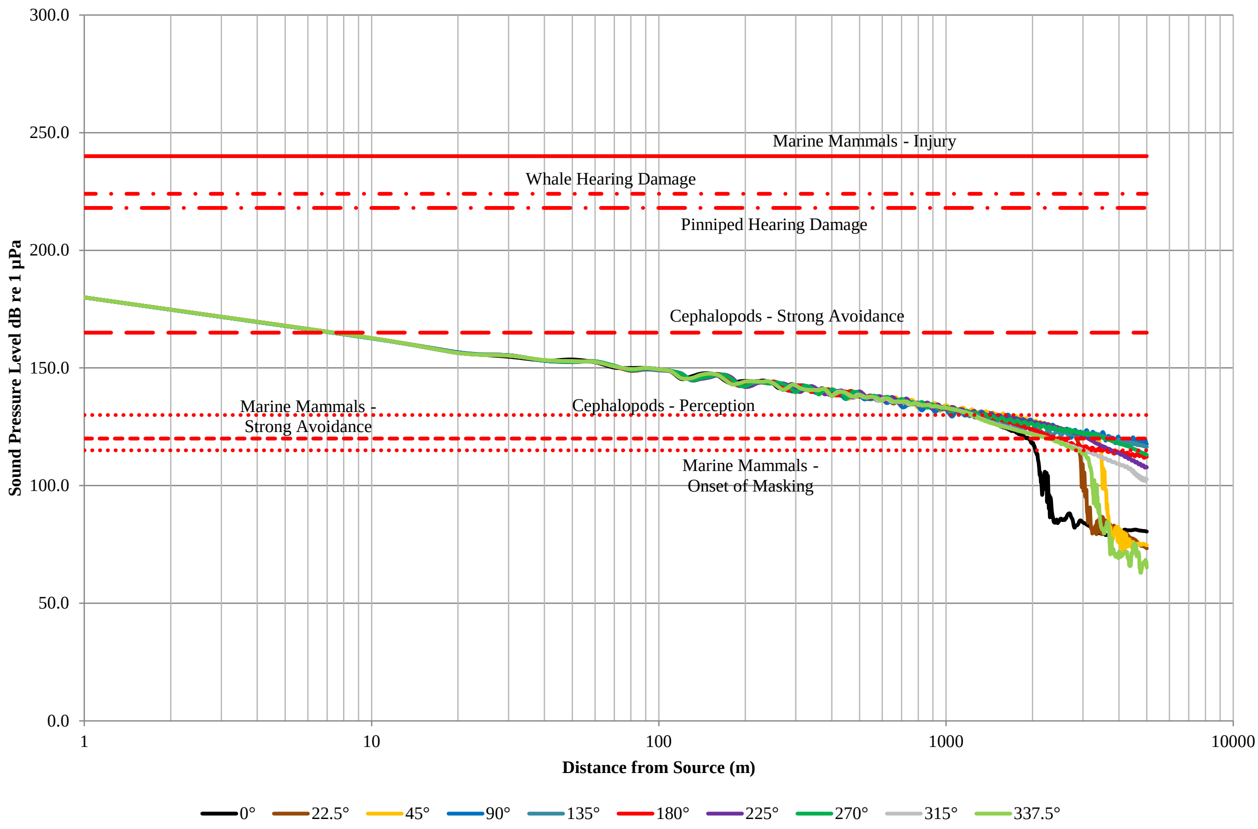


Figure 15.7j: Predicted sound pressure level (dB re 1 µPa) from shipping – South Source